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The Titanic Revisited

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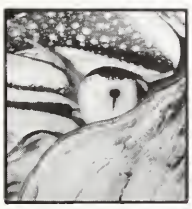

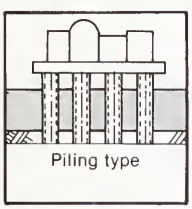

concerns

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Front Cover: Piece of *Titanic*'s ribbing, railing, and porthole. **Back cover:** video images from this summer's expedition (see story Page 2).

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The *Titanic*

Revisited

The robotic vehicle Jason Jr. leaves its "garage" aboard the manned submersible Alvin *to photograph the* Titanic. *(All photos this article and front and back covers © Woods Hole Oceanographic Institution)*

by Paul R. Ryan

The stern was the hardest place to work emotionally. The bow was still majestic. It still had its nobility and beauty. The stern was a carnage of debris, and you felt it when you were there. You knew what final tragedy had been played out on that stern section. The whole appearance of it looked violent, destructive, torn.

—Robert Ballard, July 30, 1986

- **In the debris field, a patent leather shoe, and the porcelain head of a doll.**
- **A coffee cup sitting intact primly on top of a huge, half-submerged boiler in the sediments. It must have fluttered down like a leaf through 12,500 feet of water on that fateful night and morning of April 14/15, 1912.**
- **A small safe, one of four seen, the combination lock still looking brightly polished. A British crest clearly visible. The door arm inviting an attempt to open it.**
- **A copper polished cooking kettle looking as if it might belong to one of today's fine restaurants in London or Paris. Other assorted pots and pans.**

- **Corked, chilled champagne bottles still waiting for a celebration.**
- **Numerous electric cabin space heaters, wood stoves, and lumps of coal.**
- **In the bow section, a bronze statue, perhaps of the Greek god Titan. A final omen?**
- **Portholes covered by "eyelashes" of rust, some of which appeared to be flowing from the buckled hull plating like icicles forming at the edge of a red river.**

- **Thousands of calcareous tube skeletons of the wood boring mollusks known scientifically as *Xyloredo*, which died after an orgy that devoured most of the ship's elaborate woodwork, including the deck planking.**

These were some of the verbally filtered haunting high-tech images that were returned to the world this past summer as the result of Robert Ballard's second expedition to the grave site of the *Titanic*, lost when it hit an iceberg in the North Atlantic on a clear night in 1912 (see *Oceanus*, Vol. 28, No. 4). Some 1,500 people perished, making it one of the greatest maritime disasters in history.

Ballard and a team of scientists/engineers* left Woods Hole, Massachusetts, on July 9 aboard the *Atlantis II*, the mothership of the three-man submersible *Alvin*. It took 3 ½ days to arrive near position at 41 degrees 46 minutes Latitude, and 50 degrees 14 minutes Longitude or approximately 350 miles southeast of Newfoundland.

Ballard found the *Titanic* in September of 1985 while testing an unmanned vehicle named Argo for the U.S. Navy. His second mission to the *Titanic* involved testing a prototype vehicle, dubbed "Jason Jr." or "J. J." for short that will eventually be married into one Argo/Jason system.

"Both are complementary vehicles," explained Rear Admiral J. B. Mooney, Jr., Chief of Naval Research, in a statement on 30 July 1986. "Once Argo finds an interesting object, Jason will be used for close inspection and sampling missions. Jason, when completed, will be a highly maneuverable unit that is tethered to Argo. It will have an advanced manipulator capability that will allow operation in very complex and confined regions, such as rugged undersea volcanic terrain or in wrecks. What this does is allow the eyes and hands of man to be present in dangerous areas without the risk and time penalties associated with manned submersible operations.

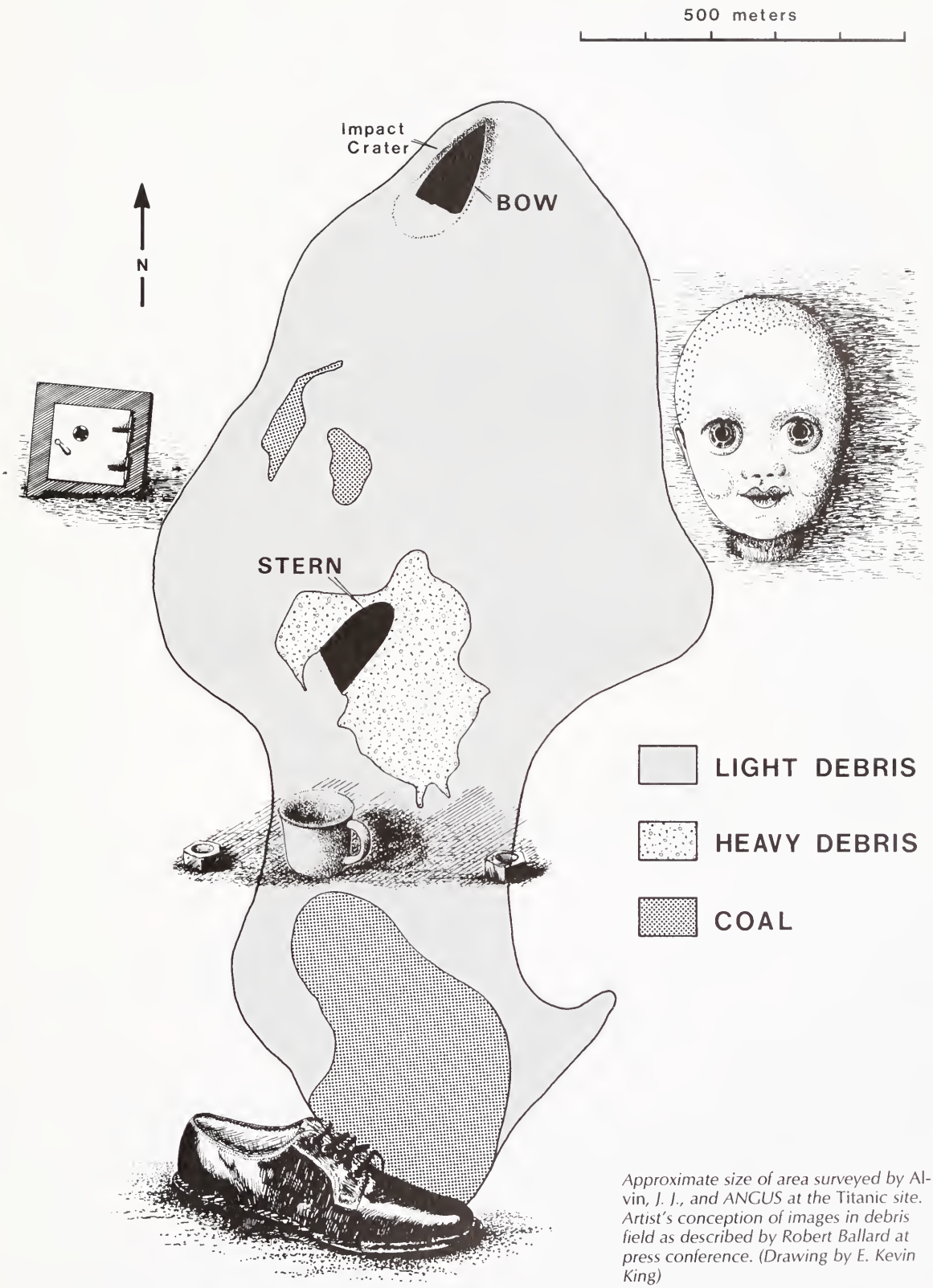
"Jason Jr., the current developmental model which will ultimately evolve into the true Jason, underwent these sea trials to demonstrate critical system performance before the Woods Hole team enters the next stage of building Jason and integrating it with Argo.

"The Argo/Jason system represents a major step forward in the Navy's capability for deep ocean search. More than 20 years ago, the *USS Thresher* was lost at sea, and required an extensive at-sea search which was hampered by inadequate search systems. Today, Argo/Jason's development offers the Navy a very advanced system capable of searching more than 98 percent of the ocean bottom."

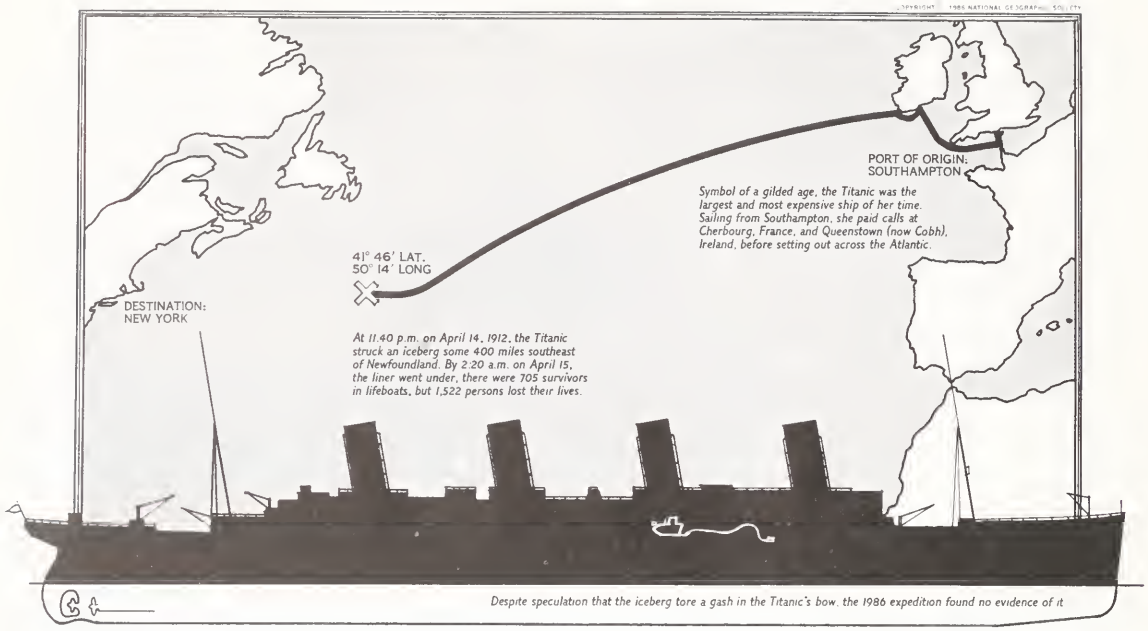
At a press conference the same day at the headquarters of *National Geographic*, in Washington, D.C., Ballard, 44, a Senior Scientist in the Ocean Engineering Department at the Woods Hole Oceanographic Institution and Head of its Deep Submergence Laboratory, stated that J. J. had performed at 100 percent of capability about 50 percent of the time, considered a very successful outing for the first time at the operational depth of about 12,500 feet. Minor problems were encountered with J. J.'s four thrusters and 200-foot electrical tether line.

The testing of J. J. was accomplished by the workhorse of the deep underwater world, *Alvin*. The tiny submersible made 11 dives out of a scheduled 12—numbers 1705 to 1716—with J. J. operational on five major occasions. The one down day for *Alvin* was because of battery problems. J. J. was tethered to *Alvin* and was housed in a basket

* Robert Ballard, chief scientist, Deep Submergence Laboratory (DSL); Chris von Alt, Jason Jr. project engineer (DSL); Martin Bowen, Jason Jr. pilot (DSL); Emile Bergeron, Jason Jr. technician (DSL); Elazar Uchupi, in charge of ANGUS Program, Geology and Geophysics Dept.; Earl Young, ANGUS team leader (DSL); Tom Dettweiler, navigation team (DSL); Tom Crook, navigation team (DSL); Ken Stewart, film processing (DSL); William Lange, film and video editing (Graphic Services); Brent Miller, Jason Jr. telemetry system (DSL consultant); Lt. Pat O'Brien, U.S. Navy, deep submersible pilot; Lt. Brian Kissel, U.S. Navy, Jason Jr. pilot; Perry Thorsvik, still photographer; Nick Noxon, U.S. documentary film producer; Graham Hurley, British film producer; Paul Halston, British cameraman; Maurice Hillier, British soundman; Chris Wentzell, British video engineer; Lt. David DeLonga, U.S. Navy, MIT/WHOI Joint Student (DSL); Lt. Michael Mahre, U.S. Navy, Submarine Development Group One, Jason Jr. pilot; and Lt. Jeffrey Powers, U.S. Navy, Submarine Development Group One, Jason Jr. pilot.



Approximate size of area surveyed by Alvin, J. J., and ANGUS at the Titanic *site. Artist's conception of images in debris field as described by Robert Ballard at press conference. (Drawing by E. Kevin King)*



R.M.S. TITANIC

called a "garage" at the front of the 25-foot submersible.

Between J. J. and *Alvin*, there were a total of 8 independent imaging systems employed on the two craft for the three-man crew to operate. These ranged from hand-held and mounted still cameras to SIT (Silicon Intensified Target) and CCD (Charged-Coupled Device) video cameras, both in black and white and color, respectively. J. J., described by Ballard as "a swimming eyeball," can "see" over a 170 degree vertical scan. At the same time, the operator of J. J. can see what the vehicle is "seeing" on a small monitor built into a compact joy stick steering device. J. J. has 4 propulsion units, or thrusters, and can be maneuvered very precisely. It carried both high-resolution color video and still cameras, operating on Alvin-supplied power of 30 and 120 volts. J. J.'s depth capacity is 20,000 feet or 6,000 meters. At one point, on the surface, J. J. slipped out of its garage, and started to sink. Divers went out quickly in a Zodiac and tied a rope with a buoy around J.J. The crew inside *Alvin*, then cut the tether and the divers pulled J.J. inside the rubber Zodiac. At another point, during a dive while J.J. was exploring the wreck, power was lost to the vehicle, and it had to be cranked back into its garage with the tether management system.

The *Atlantis II* was not alone at the site. The Navy sent a submarine-rescue vessel called the *Ortolan* to rendezvous with the Woods Hole ship on arrival. There were 109 enlisted men and six officers aboard. In addition, there were five Navy submarine officers aboard the *Atlantis II*, three of whom dove on the *Titanic*.

Ballard had taken numerous satellite fixes on his first trip to the *Titanic*, but had left no "markers" or transponders down. It was an easy matter, however, to lock into the Global Positioning Satellite (GPS) system, once on site, and find the *Titanic* again. The ship's echosounder confirmed the location of the wreck.

The divers were blessed with weather "like a no-hitter" for their mission: near perfect. After the transponders were placed in a triangular pattern to help guide *Alvin* to the wreck site, the first dive, a reconnaissance mission began. What follows are edited daily radio reports from the *Atlantis II* to Woods Hole.

July 13, 1986—Dive #1705

Ballard reported today that the *Atlantis II* arrived at the *Titanic* site at about 9:30 p.m. Saturday, and set the three-transponder net around the wreck. Weather is "excellent." They found the ship with no problem.

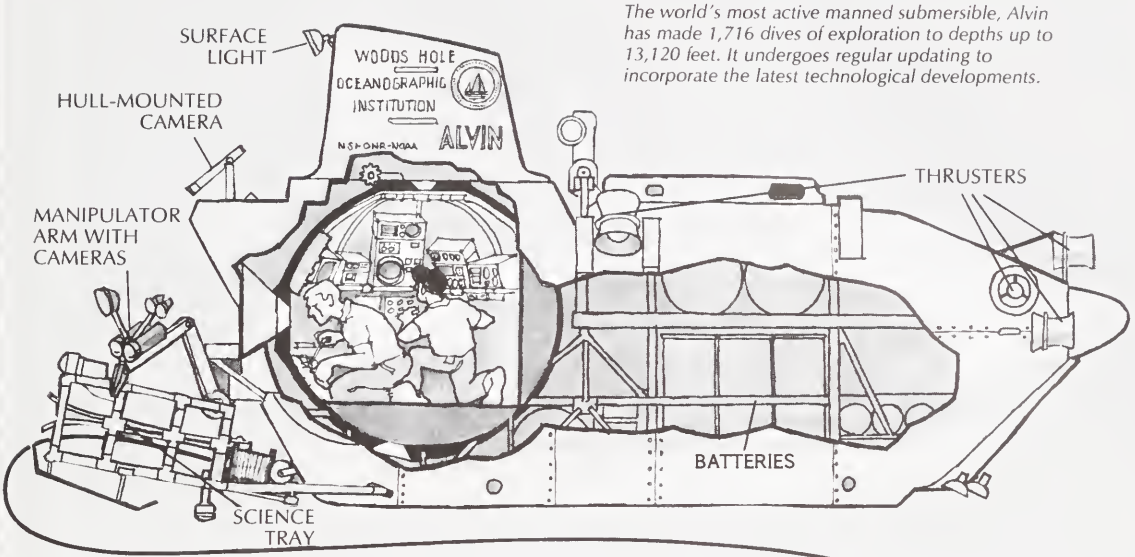
About 8:30 a.m. today *Alvin* began Dive #1705. The wreck had been spotted on the *All*'s echosounder Saturday night. Jason Jr. was tested in its garage at the wreck depth and worked very well.

Ballard said there was about a ½ knot current at the bottom and reported seeing "a huge black wall" (the starboard side of the ship). The dive was very brief and the sub surfaced early in the afternoon because of a saltwater leak into *Alvin's* battery pack. About 3 p.m., ANGUS (Acoustically Navigated Geophysical Underwater Survey) was deployed to do a 35 mm picture run through the night.

(Ballard would later liken the side of the *Titanic* to a giant sequoia. "Being in *Alvin*, was like having your nose pressed up against the bark. You couldn't see the forest for the tree."

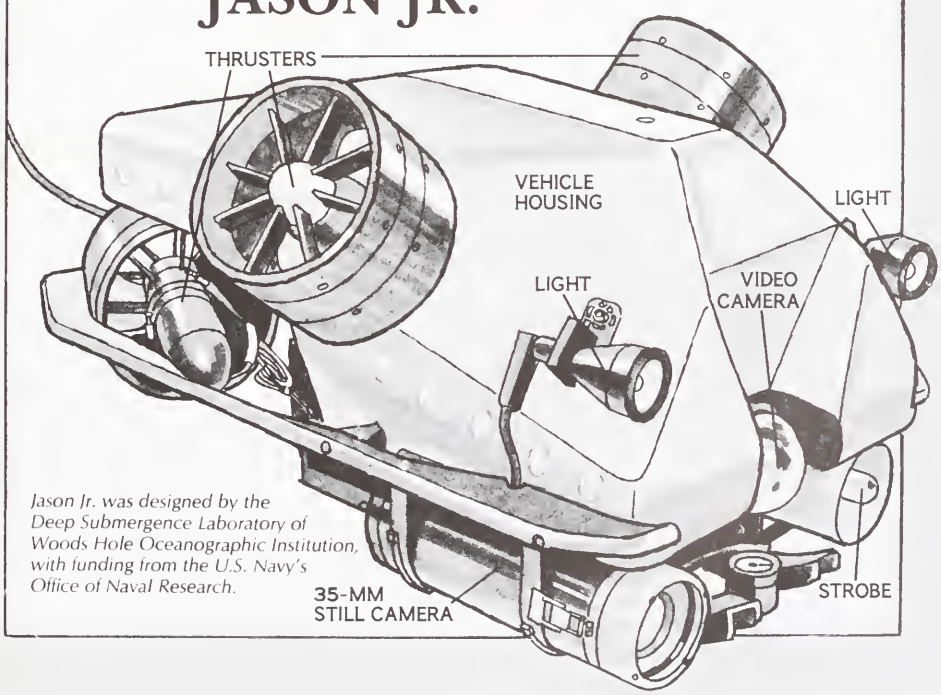
DSV ALVIN

The world's most active manned submersible, Alvin has made 1,716 dives of exploration to depths up to 13,120 feet. It undergoes regular updating to incorporate the latest technological developments.

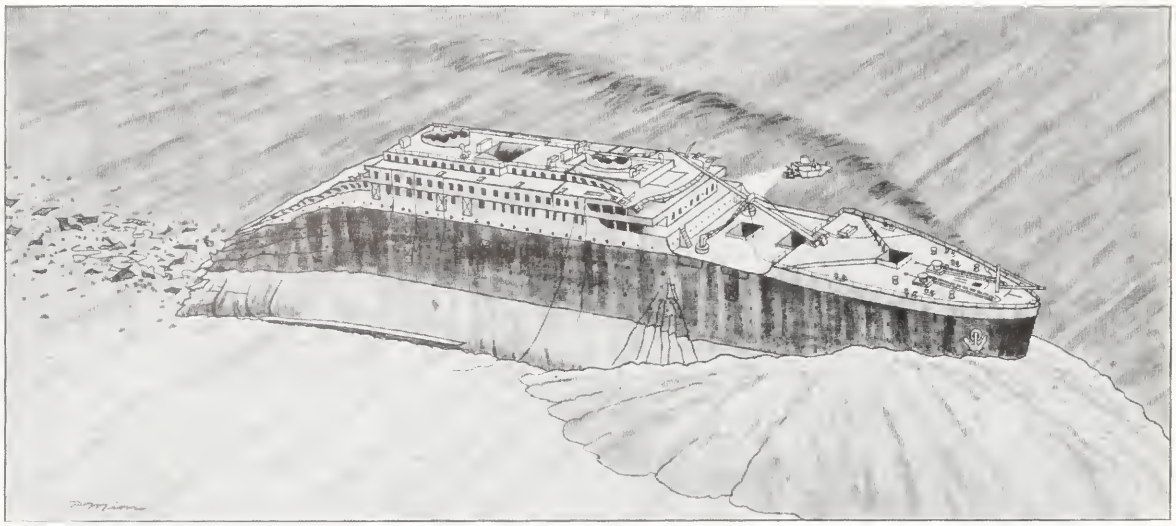


Alvin, 25 feet long and equipped to carry a pilot and two scientific observers, is linked to Jason Jr. by a 200-foot-long tether. Jason Jr.'s photographic images are transmitted to Alvin, enabling Alvin's occupants to maneuver it precisely in confined spaces.

JASON JR.



Jason Jr. was designed by the Deep Submergence Laboratory of Woods Hole Oceanographic Institution, with funding from the U.S. Navy's Office of Naval Research.



The broken hull of the Titanic *lies in about 12,500 feet of water and points north-northeast. The bow apparently plunged into the sediment at about a 45-degree angle and then skewed to port. A huge tear occurs after the second funnel of the four-stack vessel and extends to the sediments at roughly a 45-degree angle. The stern section lies some 600 meters behind the bow and faces in the opposite direction. (Sketch © National Geographic Society).*

Ballard expected to begin Dive #1706 about 8:30 a.m. Monday morning arriving at the wreck around 11 a.m. If all goes well, he will stay down until about 3 p.m. Making yesterday's first dive were Ballard; Ralph Hollis, Chief Pilot; and Dudley Foster: today's dive will be made by Ballard; Martin Bowen, J. J. operator; and Hollis. (Ballard later said that the first dive would determine the level of pilot skill needed to make future dives.)

July 14, 1986—Dive #1706

Ballard reported: "Had a spectacular day—about five hours of superb color video. We drove the whole length of the ship on both sides. We came in on the bow, sitting like a knife's edge with both anchors visible. The upper deck is dipping forward. We couldn't see the name—there are rivers of rust pouring down the side of the ship out onto the sediment.

"We saw rows of portholes, with the glass still in place. We landed in *Alvin* up on the forward deck by the mast and looked at the windlass/bitts, and chains. We then drove up around the fo'c's'le up to the starboard wing of the bridge. We landed where the wheelhouse was and saw the ship's wheel—minus the wood—all polished.

"We then came left and drove over the #1 funnel opening and out over the bow staircase, which is a truly titanic (for lack of a better word) opening. We went out onto the port side of the ship and looked into windows, back up over the ship where the stern is severed, and back down the starboard side.

"We then made three high-altitude passes up and down the ship.

"There is a very strong current—at least ½ knot, which makes maneuvering very difficult on the starboard side. We have to work bow-to-stern only because the current is like a wind blowing, preventing us from working stern-to-bow.

"It was a breathtaking experience. We plan to put Jason Jr. into the grand staircase opening tomorrow and continue surveying the ship.

"ANGUS will make another run tonight. Last night, it covered the gap in last year's data between the ship and the debris field. I understand the photos are excellent."

(Ballard would later report that surface currents ran about 2 knots, while bottom currents ran between ½ to ¾ knots.)

July 15, 1986—Dive #1707

"*Alvin* dropped down and landed about 200 meters from the *Titanic*. We drove in through the debris field. There were lots of cups and recognizable debris. We rose straight up the side of the hull of the ship and went over and landed at the entrance to the grand staircase and flew Jason Jr. down four decks inside the ship and into a room off the staircase.

"We looked at a beautiful light fixture hanging from the ceiling, drove around and back up the staircase region and filmed *Alvin* sitting on the deck of the *Titanic*. It was like landing on the moon, sitting on the deck, going four flights into the ship, and looking at the chandelier. We put J. J. back on *Alvin* and did a complete high-altitude reconnaissance with the Argo imaging system, getting beautiful downlooking pictures of the ship."

(At a later press conference, Ballard said that it was "the oddest feeling knowing that J. J. was out there looking back at us with its light coming through our portholes—it was eerie, like a close encounter.")

July 16, 1986—Dive #1708

Ballard, Bowen, and *Alvin* pilot Will Sellars landed at several sites during the course of the 9-hour dive.

The first landing site was by the wheelhouse. They sent J. J. down by the fo'c's'le first and then looked in the windows of the crew's quarters, then up the mast to the crow's nest and the brass mast light. "Beyond we explored the wheel in the bridge area," Ballard reported. "Our second stop was the boat deck and we went aft of the starboard wing. Then we went up into the first class entranceway and took J. J. through the door just a few feet and looked into the gymnasium." Next they looked into the officer's quarters and into the promenade. J. J. then went back down the stairs and penetrated deeper into the ship, viewing more light fixtures. They then brought J. J. up the stairs and out.

The next stop was the bow. They put *Alvin* on the sediment with the *Titanic* looming up and over it. They looked at the anchor. They looked for the name of the ship but it was not there; the paint was gone. They then went up and looked at wording on a brass windlass about the Glasgow manufacturer. Recovery was made under foggy conditions.

July 17, 1986—Dive #1709

"Well, there are some dives that are easy, and there are some dives that are hard—today was a hard dive," Ballard reported. "The current was very strong, and there was a lot of particulate matter in the water, so it was a hard working dive.

"The primary objective today was still imagery from the Jason vehicle and *Alvin*. With still imagery, you don't know what you've got until it's processed, whereas with the video you know what you've got immediately. J. J. had to fight hard in the current, but we worked on the main body of the ship, and tomorrow we are going to make our first trip down to the debris field. We'll just have to wait for a quieter time to try to go into the stern area.

"We did work on the port side of the ship and went into sections of the ship we had not seen before. The boat deck on the port side—we had not really explored that. Then we did go down in the tear area (at the end of the bow section where the ship tore apart) and see inside the tear portion. Also one of the expansion seams is split open and we could look inside the ship and see a wood-burning stove. There seems to have been a fair number of wood-burning stoves aboard the ship.

"We photographed the mast light—a big brass feature, and we could see a lot of hardware laying around the deck, doorknobs and things like that."

July 18, 1986—Dive #1710

"We entered the debris field," Ballard reported, "and we found large sections of the hull. It is hardly recognizable. It is just a tremendous twisted

Two bitts, used to secure mooring lines, and a railing on the starboard side of the Titanic's *bow.*

Debris litters a section of the hull of the Titanic's *stern, peeled outward by the force of the great ship's destruction. A 200-foot section of the stern was found intact, but rotated 180 degrees, with parts of it buried in the ocean bottom, a third of a mile south of the bow section.*

pile of wreckage that is very difficult to maneuver in because it is so irregular and overhanging. We inspected a large part of it, almost the size of a city block, and then we worked around that large area. Radiating out around the area is a tremendous number of artifacts. It is actually like going to a museum. There are just thousands and thousands of items all over the bottom.

"If we were ever going to see any human remains we would have seen them in this area, the closest we saw was a shoe, but no human remains at all.

"We did find the ship's safes. They were rather spectacular. The one we went up to had a big handle that looked like it is either bronze or gold. It had a dial and beautiful British crest. It was polished clean. We went over with the manipulator (*Alvin's* mechanical arm) and grabbed hold of the big handle, but the safe wouldn't open. We then took a picture of it and moved on.

"We saw chamber pots and wine bottles and stained glass windows. . .we did a lot of beautiful closeup photography of these artifacts. Everything you could think of was laying all over the bottom. The champagne bottles, by the way, still had their corks in them.

"The current wasn't bad. It was easy to negotiate through the debris field, except for the stern area—that was a little dicey.

"Tomorrow Martin and one of the naval officers are going down and they are going to be using J. J. on the bow. We are going back to the main part of the ship, and they'll be doing some high-altitude imaging runs."

July 20, 1986—Dive #1711

Lt. Jeffrey Powers, U.S. Navy: "I made my first dive today. Along with me were Bowen and the pilot. We went to the bow and had some trouble with Jason Jr. We are correcting that problem now. Then we made some runs over the top of the bow section and looked for some places where we can deploy Jason Jr. in the next couple of dives. I was really impressed with the amount of decay, rust, and devastation that I saw. The cables and steel twisted all around. Kind of chaos and calamity. But it also was kind of peaceful and restful. The silent ship resting there, slowly dissolving in the ocean."

Ballard: "*Alvin* experienced a battery problem, so we didn't go in the water yesterday. Instead we launched ANGUS, the remote camera system, and finally after all this time successfully located the stern section. It turns out that at least a third of the stern section is intact. We were surprised after looking at all the wreckage to find that much of the stern still in one piece. Tomorrow the mission is to explore the stern section and try to see, hopefully, the name Southampton* on the stern. We have not

* Ballard erred. Liverpool was the home port of the *Titanic*.

seen any of the stacks; they continue to elude us; but we did find another of the ship's telegraphs, and we've been locating more and more boilers. We are continuing to expand our coverage."

July 21, 1986—Dive #1712

"We landed on the bottom in the debris field about 150 yards from the stern," Ballard stated, "and drove up and did some high-altitude flying about that part of the ship trying to familiarize ourselves since we'd never been there before. The large debris field begins 600 meters south of the main bow section and extends another 600 meters further south. We used our Argo camera mounted on *Alvin*. Then we located the very stern of the ship and went down and landed on the sediments.

"The stern is just sitting upright on the bottom. The front portion has buried itself deep in the sediments. The name of the ship was gone. Evidently it was just painted on and it just rusted off. There is no paint on the exposed part of the hull of the ship anywhere. The propellers are buried, but the rudder is quite visible.

"Then we rose up and sat on the stern. At the very end of the stern, we placed a Titanic Historical Society plaque commemorating those who perished on the ship. We thought the stern was an appropriate place to place it since that is where most of the people died. It was the last part of the ship to go under.

"Then we made a series of runs along the stern section, which is roughly 250 feet long, to the tear at the other end, and surveyed that whole section. Then after that we went and drove through the debris field documenting all the different artifacts both on still and videotape."

July 22, 1986—Dive #1713

"This dive was on the main section of the ship," Ballard reported. "The major goal today was to photograph the entire exterior surface of the ship. I can almost say now that there is not a square inch of the *Titanic* that has not been photographed in beautiful detail in color.

"We ran along the entire length of the hull along the waterline, along the sediment line—looking for the gash—and could see absolutely no evidence of a gash, although we did see several of the large plates buckled.

"So the question is were we deep enough to see the gash? I know up in the bow, the very bow portion, the gash is not visible because the ship is buried so deep in the sediments. But as we got further aft around the bridge line and aft of the bridge, we were below waterline on the hull of the ship. We could see the water intakes, we could see the copper-painted hull, so we were definitely below waterline and down where the gash should be from the bridge on and didn't see anything. In fact, we were all the way down near the end at the stabilizing fins on the hull that helps against rolling.

Rites of Passage, Drip, Drip, Drip

When you close the hatch on Alvin *at the surface, you begin a condensation process. This is not generally known by a person making his first dive in the tiny three-man submersible.*

Veteran divers tend to listen to classical music or nod off on the trip to the bottom—in the Titanic's *case 2½ hours. Every half hour there must be communication with the* Atlantis II *on the surface. Failure to communicate leads to automatic emergency procedures, such as a call to the Coast Guard. The pilot is encouraged to stay awake.*

On one of the Titanic *dives, a U.S. Navy officer began to notice a drip, drip, drip, splat, splat, splat, coming from the hatch area as they descended to 12,500 feet. "My God! What's that," he shouted in alarm.*

Robert Ballard, looking up at the hatch as he has more than a hundred times, exclaimed, "We've had it. We've sprung a leak, we're sinking."

After allowing for a moment of general panic to grip the naval officer, Ballard grinned and explained that the drips were the result of condensation caused by the extremely cold temperatures outside the submarine at depth. About that time the plexiglass in the conical viewing ports began to move slightly inward from the outside pressure, another normal occurrence.

We didn't see any suggestion of a gash. But we did see several places where the hull is buckled in and plates were sprung—the rivets were sprung. Whether that was caused by the iceberg encounter or whether that was caused by the ship's encounter with the bottom, we'll just have to sit down with a lot of people and look at it. (Ballard later theorized that the iceberg popped rivets along the steel hull plating and that water had thus entered in this fashion rather than from a big gash. It would also explain why passengers had hardly noticed the collision with the iceberg.)

"We travelled all the way back to the tear on the starboard side. We looked in the tear near the # 3 funnel (looking forward from the severed part of the bow section). It's just a chaotic jumble of wreckage in that area. The tear is at a 45 degree angle. We filmed all the windows in the hull surface into the officer's quarters, the radio room, the captain's sitting room—and then we filmed along the promenade, looking in the windows of the promenade deck.

"We did not deploy J. J. today because of a motor problem. We concentrated on long photographic runs along the entire length of the ship. We circled the ship at least a half a dozen times, clockwise. We're very rich in images. It's going to take many experts years and years to totally absorb what

Diving on the Titanic

There is no movie I've seen or book I've read that could equal the eerie scene that I witnessed at the Titanic *graveyard. The ship is draped in a cloak of flocculant brown ooze that drifts away when disturbed. The windows, which are clean on the outside, are sometimes coated on the inside, hiding the cold, dark secret of the contents of the rooms, a 74-year-old mystery. What remains of the* Titanic *is a partially decomposed ghost, blown apart at the third stack, spilling its innards all over the seafloor.*

Diving on the Titanic *was like participating in a ghost story. It reminded me of the picture "The Flying Dutchman," a dark, cold ghost ship with moss hanging from the rigging.*

Our normal dive day starts before 6 a.m. with a predive check of all systems. Alvin *is usually launched and submerged before 8 a.m. The* Alvin *pilots (there are presently nine) are a very special breed, hand picked for the combination of skills, character, and personality required for this occupation.*

Alvin *is probably the most advanced deep submersible in use today. The propulsion system has been completely updated with direct drive brushless D.C. motors. Battery power has been doubled. Instrumentation inside the sphere has been completely renovated. External viewing lights have been increased to 11 for better viewing and video.*

We are continuously reviewing the needs of science. At this time, we have a new navigation system under development. We also are in the process of acquiring new manipulators for Alvin, *and a precise depth system. In the near future, we hope to have a system that will give the scientist a detailed, real-time topographical chart of the bottom area on which* Alvin's *tracks may be superimposed.*

—Ralph Hollis,
Chief *Alvin* Pilot

we've done. We'll be sending two naval officers down tomorrow (Dive #1714) for part of the training program with the Navy, and then the final day we will attempt more Jason penetration work, (Dive #1716)."

July 23, 1986—Dive #1714

Lt. Brian Kissel, U.S. Navy: "We did not operate J. J. today. We had mechanical problems. Nevertheless, it was really an eye-opening dive, much better than all the video that we had seen so far. We had much more depth and field of vision than you can experience with video or still photography. And you get much more of a feeling of the expanse of the wreck and the quiet tomb-like atmosphere down there. We were very happy to go down as it is just the end of the expedition. And having had significant problems with Jason Jr. throughout the course of the expedition, we were wondering whether we'd make it down or not.

"We did do some still photography and used the video camera. We worked in between the bow and the first class cabins in the bridge area, and in the cargo loading area."

Lt. Mike Mahre U.S. Navy: "The trip down today was the icing on the cake. It was super. I don't know when I've had a more thrilling experience—maybe, the first time I saw the Grand Canyon.

"It's always better to see something in person; pictures just don't do it justice. When you're down there, looking at it close up, you really get a feeling for it, for its immensity, and you get that sense of awe. You look at the bow section—straight down from the top of the bow—and it looks like a tremendous wall, yet two-thirds of the bow section is buried in mud. We couldn't see anything of it. It's a big ship and we really didn't get that impression until we were there looking at it. You won't see that in pictures.

"We were sorry about J. J., but that's what research and development is all about. You go out and try something, and if it doesn't work, you fix it up and make it better next time. So that's what we're doing. We're getting closer and closer to a decent finished product. That's where we're headed. I was not disappointed. I'd dive again in a heartbeat."

July 24, 1986—Dives #1715 & 1716

Dive #1715 was aborted after problems were experienced with J.J. on the way down. It was decided to return to the surface to correct the problem. A second dive (#1716) was made the same day.

Ballard: "Today was clearly the best dive (#1716) of the entire series. Jason Jr. performed flawlessly; just did a beautiful job, and we took our most dangerous penetrations today. We landed the submarine initially on the bow and worked that area with J. J., but then we moved up to the port side of the ship near the wheelhouse just flanking the first officer's cabin near the bridge, landed *Alvin* on the boat deck, and then sent J. J. over the side of the ship and entered the promenade deck from the side of the ship and went in and explored that area.

"In fact, we went up to a brass plaque that said *'This door for crew use only.'* We could read it very clearly. We had a problem at the end when J. J.'s cable became entangled in some of the wreckage,

X-ray of the burrows of the wood-boring mollusk Xyloredo ingolfia *Turner (Family Pholadidae) in a wood panel submerged for almost a year at 3,644 meters depth at the WHOI/ALVIN deep ocean research station 700 miles east of New Jersey. The panel was 2.5 centimeters thick and asbestos backed. Note the calcareous lining of the burrows and the shells with which these animals bore. (Photo courtesy Professor Ruth Turner, Harvard University, Museum of Comparative Zoology)*

but we were able to work it free and return J. J. back to *Alvin*.

"After the dive, we recovered our transponders. We're now on our way home."

***

When Ballard reported to the press in Washington that he had spotted a bronze statue in the bow section of the ship, possibly of the Greek god Titan, he revived memory of Morgan Robertson's 1898 novel entitled "Wreck of the Titan." The novel was about a large luxury liner of almost the same dimensions as the *Titanic* which hit an iceberg on her maiden voyage and sank in the North Atlantic with great loss of life. After the sinking of the *Titanic*, 14-years after the fictional *Titan*, the novel was seen by some as an "omen" bordering on the occult.

The stern section's distance from the bow led Ballard to the conclusion that the *Titanic* did not arrive intact on the bottom. He believes the ship either broke apart on the surface as it went down or that the shear occurred at about 1,000 feet when the stern section may have imploded. At his Washington press conference, Ballard disclosed that the stern section of the *Titanic* had actually twisted about 180 degrees out of phase so that it now faces opposite the direction of the bow, south-southwest. In addition to the artifacts already mentioned, four of the ship's huge boilers were spotted in the debris field, one with a coffee cup resting on top.

Two of the most interesting observations from a scientific point of view were the "rivers of rust" found flowing off the hull plates, and the almost total absence of any wood, or, for that matter, any organic material with the exception of a patent leather shoe. Last year's photos had led Ballard to believe that the deck planking and other wooden items had survived. But on close inspection, it turned out that the planking, wheelhouse, and other elegant interior areas had been "eaten right down to the nub" by wood-boring mollusks. Work done at a nearby site in the North Atlantic by Professor Ruth Turner at Harvard and others had indicated this would be the case. Corrosion specialists at the Massachusetts Institute of Technology plan to study the video tapes of the rust for clues to corrosion processes at great depth.

Ballard said at a brief dockside news conference on his arrival back in Woods Hole that he was "confident the *Titanic* can never be salvaged and will never be raised. The bow section is in 50 feet of mud; the ship is in a state of deterioration and is very fragile. Any attempt to salvage will break it up." In fact, in addition to *Alvin*, only France's submersible *Nautile* and the U.S. Navy's *SeaCliff* are capable of operating at the *Titanic's* depth. It is Ballard's position that the *Titanic* site should remain an undisturbed memorial to those who died in the 1912 tragedy.

The 1985 expedition that found the *Titanic* was a joint French/American project. The French did not participate in this year's expedition because of a reported lack of funding.

A cargo crane extends beyond the starboard side of the Titanic*'s stern section in a photograph taken from the towed camera sled* ANGUS.

Robert Ballard, right, discusses dive strategy with U.S. Navy officers aboard Atlantis II. *Martin Bowen, second from left, a member of the Deep Submergence Laboratory at WHOI, operated Jason Jr. on many of the dives. After the expedition, in the spirit of this past summer's popular film "Top Gun" starring Tom Cruise, Secretary of the Navy John Lehman dubbed Ballard the Navy's "Bottom Gun" and presented him with a baseball cap so inscribed. (Photo U.S. Navy/Woods Hole Oceanographic Institution)*

An officer's cabin window on the starboard side of the Titanic*'s boat deck appeared as the manned submersible* Alvin *surveyed the wreckage of the doomed ship.*

Looking straight down from the top of the Titanic*, a photograph taken from ANGUS reveals a tear and collapsed decks on the forward section's starboard side. The hull is buckled outward, showing windows into the liner's promenades.*

A brass capstan on the bow. An Explorer's Club plaque was placed on a windlass in this region.

The only thing raised from the *Titanic* during the summer's expedition was a small piece of rusted cable that hooked on to the ANGUS sled. It was thrown back overboard. The divers saw no evidence of human remains, which was predicted by a deep-sea microbiologist at WHOI last year.

None of the *Titanic's* four huge smokestacks were spotted in the debris field. Either they lie outside the area surveyed or they disintegrated on the way down from the surface.

The wreckage of the *Titanic* lies to the east of a canyon on the continental rise. Ballard said the canyon may have acted as a barrier that prevented the ship from being swept away by the mud slide or turbidity current that followed a large submarine earthquake in 1929, which severed several transatlantic cables.

By the end of the expedition, *Alvin* and J. J. had spent 33 hours surveying and photographing the *Titanic*, and ANGUS had spent 100 hours taking more than 57,000 pictures. For Ballard's part, he plans to finish the Argo/Jason project and then use the vehicle to explore the mid-ocean ridge system, a range of submarine mountains that stretches more than halfway around the world.

Ballard said at dockside on his return that he hoped he had satisfied "everyone's curiosity," and that "there will be no need to ever go back.* I have no desire to do so," he said.

Well, maybe not everyone's curiosity. I'm sure members of the Titanic Historical Society will debate the absence of any gash on the starboard side and Ballard's popped rivet theory for her sinking for a long time to come. Then there are those who are probably wondering what's in those four safes. There is an old adage that "curiosity killed the cat, but that satisfaction brought it back." There may yet be another tale in the *Titanic* telling.

Paul R. Ryan is Editor of Oceanus*, published by the Woods Hole Oceanographic Institution*

* Ballard is writing an article for *National Geographic* magazine on the second expedition to the *Titanic*. It will be accompanied by many new photos of the wreck. In addition, he plans to write an illustrated book about his *Titanic* adventures.

Low-Level Radioactivity in The Irish Sea

by James H. W. Hain

In its January 1986 report on radioactive waste, Britain's House of Commons Environment Committee termed the Irish Sea, "the most radioactive sea in the world." The radioactivity is largely the result of sea discharges from the Sellafield Nuclear Fuel Reprocessing Plant on the British coast at Cumbria (Figures 1 and 2). For nearly two decades, the Irish Sea has been a sea of strong emotions, divergent opinions, and varying interpretations of the available facts. The nuclear industry, governments, environmental groups, scientists, and citizens have all taken part. The understanding and decisions are made difficult by technology, concepts, and statistics that are not readily understood. At the outset, the Committee stated, "Of all the inquiries the Committee has tackled so far, this is undoubtedly the most technically difficult."

The Sellafield installation is actually a sizeable nuclear complex. On, and nearby, the 600-acre site, are the reprocessing plant, storage ponds, the four Calder Hall nuclear reactors, a prototype Advanced Gas-Cooled Reactor (AGR), a new thermal oxide reprocessing plant (THORP) under construction, silos for radioactive liquid waste, and the nearby Drigg solid waste disposal site.

Sellafield has a number of distinctions. It is

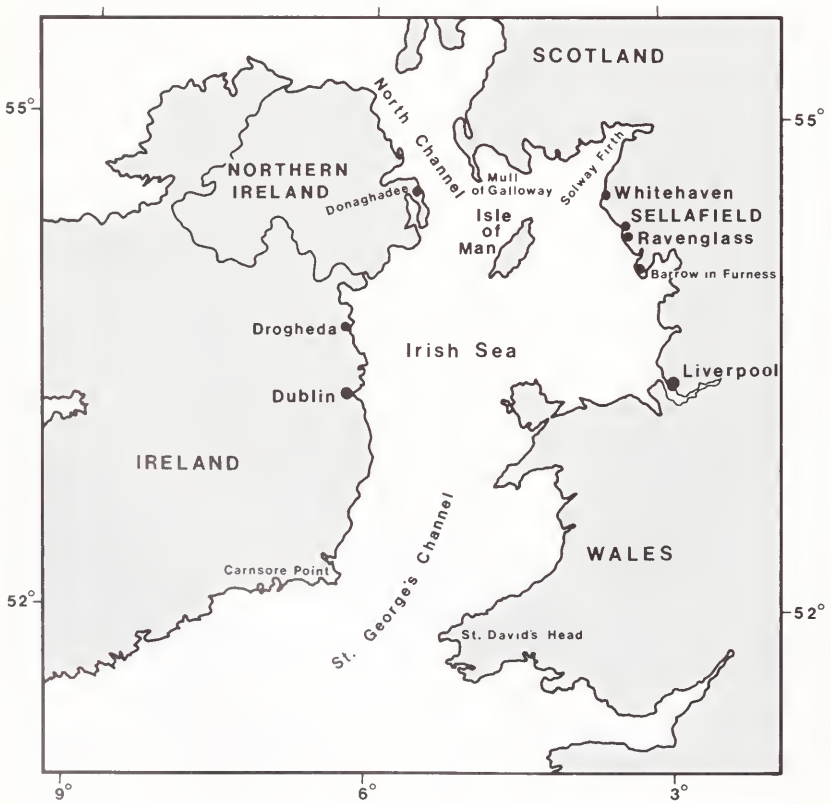


Figure 1. The Irish Sea.

PRIMER
For readers unfamiliar with radiation terminology and concepts, a primer appears on page 27.

Figure 2. The Sellafield plant of BNFL on the Cumbrian coast. On the right are the four 50-megawatt reactors at Calder Hall; on the left the sphere contains the 33-megawatt prototype Advanced Gas-Cooled Reactor (AGR), now being decommissioned. The original "Windscale Piles" are immediately behind the tall stacks. The reprocessing plant is in the center of the site, and the route of the discharge pipelines to the sea can be seen on the extreme left. (Courtesy British Nuclear Fuels Limited)

the world's largest nuclear reprocessing site.* The site contains the oldest operating commercial nuclear power plant. It also is believed to be the largest repository of stored radioactive materials in the world. Prior to the April 26 Chernobyl incident, it was the site of the world's only known graphite-core reactor fire (October 10, 1957). It is the site of Europe's largest civil engineering project (the THORP plant). It has emitted more radioactive discharges than any other site. Largely because of Sellafield, Britain has discharged more radioactivity to the sea than any other nation. Finally, it is perhaps the world's most controversial civilian nuclear power installation.

The history of Sellafield goes back to the 1940s. In a secret Defense Ministry project in the late 1940s, nuclear engineers built two nuclear "piles" to produce weapons-grade plutonium. The site was then called Windscale. In Britain, as elsewhere, military nuclear efforts evolved to produce civilian nuclear power. In 1956, Britain opened the world's first commercial nuclear power station, called Calder Hall, on the site. The reprocessing began at Sellafield in 1952, with larger facilities coming into operation in 1964, and expansion and modification continuing to the present. The sea discharge of liquid radioactive waste dates back to the 1950s.

Largely as the result of public outcry, Sellafield, nuclear fuel reprocessing, radioactive waste, the Irish Sea, and the health effects of low-level radiation have been examined in some detail. While Sellafield has a record of high discharge levels in the 1970s, and sporadic radiation incidents and accidents, the record also shows markedly decreasing discharge levels in the 1980s. The Irish Sea, however, has been, is still, and likely will be for some time, one of the world's most radioactive seas.* Radiation levels found in the seawater and on the sea bottom are magnified hundreds and sometimes thousands of times along the pathway to man. To date, doses received from this source have not exceeded internationally-established limits, although in the face of uncertainty, coupled

* Other nuclear reprocessing plants in coastal locations are at the Cogema facility, at Cap de la Hague in Normandy, France; and the Bhabha Atomic Research Center, Trombay, Bombay, India.

* Eric H. Tucker of British Nuclear Fuels Limited advises (based in part on The House of Lords Select Committee July 1986 Report on "Nuclear Power in Europe") that: the natural radioactivity of the Dead Sea and the Great Salt Lake (Utah) result in greater total activity per unit volume than concentrations in the Irish Sea even in the vicinity of the Sellafield outfall.

with new findings, discharge limits and human dose limits have been continually revised downwards.

Incidents and Inquiries

In its 40-year history, Sellafield has a record of what environmentalists say have been more than 300 radiation incidents. After the October 10, 1957, reactor fire, the government statement was reassuring—and uninformative. After a few days, it was disclosed that a number of workers had been contaminated, milk within a 14-mile radius was ordered destroyed, and a contaminated area of 200 square miles was reported. In 1973, an accident to one reprocessing unit contaminated 35 workers with ruthenium-106. The plant was cleaned up, and is again in use, but in a different capacity. By 1977, while expansion plans were approved by the government following a public inquiry, government officials noted the depth and magnitude of public opinion. A more recent focusing of public attention stemmed from a November 1983 British television documentary entitled, "Windscale: The Nuclear Laundry." Three weeks later, plant washings were accidentally transferred to a sea tank and subsequently discharged to the sea. Widespread contamination of public beaches occurred, followed by a major clean up. At about this time, the name was changed from Windscale to Sellafield—in what has been termed a clear public relations maneuver to divert public attention. In January of 1985, the Environment Committee began its inquiry into radioactive waste. In July of that year, British Nuclear Fuels Limited (BNFL) was convicted on four criminal charges relating to the beach contamination incident.

This year, 1986, again contained recurring incidents. In January, nearly a half ton of uranium was dumped into the Irish Sea. A week later, a mist of plutonium nitrate vapor contaminated 11 workers in a reprocessing building. In February, the government appointed a 12-member panel to begin a detailed safety audit of Sellafield. Finally, in the *Sunday Times* of February 16, it was reported that Sellafield discharges for the period 1953–55 may have been underestimated by a factor of 40.

In its report, the Environment Committee found, "Not only is [Sellafield] not glamorous, it has become a by-word for the dirty end of the industry in the nuclear world. The impression it conveys is one of error and misjudgement. Against this background, it must be difficult for the industry to expect its figures on dose rates, safety levels, and minimal risk to be believed by the public."

Not everyone agreed with this appraisal.* Joseph Lelyveld in the *New York Times* of April 6, 1986, reported that a member of Prime Minister Margaret Thatcher's Cabinet, Peter Walker, the Secretary of Energy, dismissed the committee's report as "non-sense," saying Sellafield was "good for Britain and good for the economy." There is no doubt that the industry provides jobs, more than 10,000, and has provided economic rescue for West Cumbria following the closing of steel mills and coal mines.

The harsh words expressed in the committee's report, however, were not one sided. Certain of the environmentalists, namely the Greenpeace organization, had much of their testimony discredited. The report reads, in part, "At times, the actions of some environmental groups are even more blameworthy than those of the industry. We were made forcibly aware of this by statements given in evidence by Greenpeace. Greenpeace stretched a passing reference to the point of extreme distortion, just for the sake of sensation or, more seriously, in order to mislead the Committee. Greenpeace's credibility as witnesses was certainly diminished in our eyes and considerable doubt accordingly thrown upon the rest of the evidence they submitted."

The Irish View

In Ireland, as elsewhere, the views differ. Dick Spring, Irish Minister for Energy, on March 21, 1986, called for the minimization and early elimination of the Sellafield discharges. He further stated, "The safety record at this plant has been less than satisfactory, and we have lost confidence in their safety procedures."

On the other hand, George Duffy, Chairman of the Nuclear Energy Board in Dublin, on March 14, 1986, stated, "The level of radioactivity in the Irish Sea recorded by the Nuclear Energy Board's own Radiation Laboratory, and Irish college and university researchers, permits the Board to clearly state that radiation from this source does not pose a significant health hazard to the Irish public. What worries me. . .is the four 30-year-old Calder Hall reactors on the site. If I were offered the choice of stopping the reprocessing completely at Sellafield or shutting down the reactors, I would without hesitation choose shutting down the aging reactors. It is my opinion that they pose a greater health risk to us on this island than the much discussed discharges of radioactivity into the Irish Sea."

The Nuclear Fuel Cycle

Economic and strategic factors are used to justify the re-cycling of nuclear fuel. Spent, or irradiated fuel is not necessarily waste, since it typically contains up to 96 percent unburned uranium. Also, since plutonium is a man-made by-product of nuclear fission, and can only be obtained from reprocessing, reprocessing is of interest because of plutonium's use in the new Fast Breeder Reactors (FBRs), and in military weapons applications.

For continued operation, nuclear power plants require periodic replacement of the reactor core fuel, and about a third of the fuel is replaced every 12 to 18 months. A standard nuclear power reactor discharges about 30 metric tons of spent fuel rods each year. Reactors built in Britain prior to 1971, about 26 in number, are of the "Magnox" type. The name comes from the magnesium alloy casings (also called "canning" or "cladding") inside which the natural uranium fuel rods are housed.

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* *Radioactive Waste—The Nuclear Industry's Response to the Environment Committee's Report*, was published in July 1986 by British Nuclear Fuels Limited and a consortium of industry and government agencies. It is available from Her Majesty's Stationery Office, London.

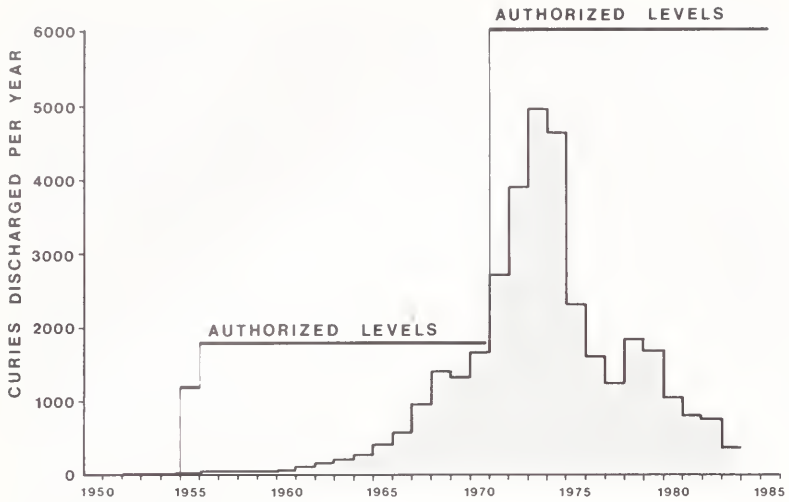
Figure 3. Reprocessing fuel from overseas involves sea transport of spent nuclear fuel. Several purpose-built ships owned by BNFL's subsidiary, Pacific Nuclear Transport Limited, or by BNFL itself, are used. The larger ships each have a capacity of 28 flasks and a total load of 60 tons of spent fuel. The fuel flasks are offloaded at the BNFL terminal at Barrow. (Courtesy BNFL)

Inside the reactor, the fuel is placed in a graphite moderator, cooled by carbon dioxide. The reprocessing at Sellafield was originally established for the reprocessing of this Magnox-type fuel.

The reprocessing takes place in several stages. But before any reprocessing can begin, a period of submerged storage is required, as the spent fuel is typically hot and radioactive upon its removal from the core. Therefore, the fuel is placed in water-filled storage ponds at the reactor site for about 6 months (water is a very effective radiation shield and dissipator of heat) to allow the radioactivity and heat output to decline. Later, after transport to the reprocessing site (Figures 3 and 4), it typically receives additional time in fuel-storage ponds. In the first stage of the actual reprocessing, the Magnox cladding is mechanically stripped off the uranium rods. The stripped cladding becomes stored solid radioactive waste. The uranium rods are next put through a series of acid baths and treated chemically to separate out the unburned uranium, the plutonium, and the "fission products" (radioactive debris from the atoms split by the chain reaction). The uranium and plutonium can then be stored and re-cycled.

More recently, Britain has developed Advanced Gas-Cooled Reactors (AGRs), which burn more efficiently. Here, the fuel is composed of uranium-oxide pellets encased in stainless steel. But, the existing facility cannot reprocess fuel from these newer AGR reactors. To accommodate this fuel, Britain decided in 1977 to build a new thermal-oxide reprocessing plant (THORP) at Sellafield. The THORP plant, scheduled to be completed in 1992, is to treat 6,000 tons of spent fuel from Britain and abroad in its first 10 years. When completed, it will be the largest such facility in existence.

Figure 4. The fuel flasks are transferred to special BNFL-owned railway cars for transport to Sellafield. The fuel transport flasks comply with the regulations of the International Atomic Energy Agency. (Courtesy BNFL)



Discharges to the sea of "total alpha" from the Sellafield site. Not shown by the graph is that the total alpha radiation is a fraction of the total radioactivity discharged. For example, in 1978, the total alpha was 1,800 Curies, while the total radioactivity discharged was 218,000 Curies (Data from G. J. Hunt, MAFF Aquatic Monitoring Reports)

In all its reprocessing operations, Britain depends heavily on foreign contracts. British Nuclear Fuels Limited (BNFL), the government-held company operating Sellafield, has reported contracts with utilities in Japan, West Germany, Switzerland, Italy, the Netherlands, Sweden, Spain, and Canada. The business thus generated is sizeable—and may form up to two-thirds of the total revenues. In 1985, for example, BNFL reported profits from foreign contracts totalling $188 million. BNFL also reported that a large portion of the construction costs of the new THORP plant, some $2 billion, have been underwritten in advance by orders from foreign utilities.

Clearly, Britain, like several other countries, has a large and strong commitment to nuclear power. This is based on both economics and resources. Britain has no uranium of its own. This, at a time when uranium prices were high, led to an interest in reprocessing. Further, because of a shortage of land for storage (like Japan), an interest in discharge was created. Since then, the nuclear business has become a strong and economically attractive undertaking.

However, since the 1970s, when much of the Sellafield planning took place, the world has undergone several changes:

1. Electricity demand in Britain is significantly less than forecast in 1978,
2. Nuclear power programs around the world have fallen well short of the growth expected in 1978, and will continue to do so for the foreseeable future,
3. New and very high-quality uranium reserves have been found in Canada and Australia,
4. The expected shortfall in uranium supply relative to demand has not materialized. The price of uranium has dropped dramatically, and is expected to remain low for some time to come.

These factors may influence the activity at Sellafield, although it is unlikely that they will change the direction.

A second set of factors has come to the fore since the 1970s—an increasing concern with the effects of radioactive waste on the environment, and on human health. The problem with reprocessing, from the environmental point of view, is the large quantities of radioactive waste it produces.

Sellafield Discharges

There are two basic methods for dealing with radioactive waste: containment and discharge. With containment, the philosophy is to isolate the waste to prevent exposure to harmful effects. With discharge, the philosophy is to release the wastes in such a way that dispersion and dilution render them harmless. Both treatments have many facets, and both methods are acknowledged to be imperfect. Sellafield, like other installations, does both. In this article, the focus is on the sea discharge of low-level* liquid wastes.

The sea discharges from Sellafield contain a suite of radioactive components, a suite that varies over time in both composition and quantity relative to the operation of the plant. The radioactive discharges arise from a number of sources—fuel storage ponds, reprocessing streams, and plant-cleaning operations. Using cesium-137 as an example, from 1970 to 1974, 70 percent of the discharge came from the storage of irradiated fuel rods under water in the cooling ponds. (Ironically, the spent Magnox fuel is shielded in storage ponds, but the submerged cladding deteriorates, releasing radioactivity to the pond water—which then must be dealt with.) Since 1974, more than 90 percent of the radioactivity has come from storage, and less than 10 percent from fuel reprocessing. In normal practice, a fraction of the pond water is

* Low-level wastes (LLW) are generally classified as high-volume waste of low radioactivity. The term is felt to be somewhat misleading, as LLW sometimes contains long-lived alpha-emitters which may be potentially harmful.

continuously replaced and discharged. This sea discharge takes place, at present, through twin pipelines, 0.3 and 0.5 meters in diameter, and some 2.5 kilometers long, to the seabed at a depth of about 20 meters. Low-level radioactive waste is discharged, heavily diluted, in quantities of up to 1 million gallons of water per day. The most significant discharges from Sellafield, because of their long half-life are cesium-137 and -134, ruthenium-106, strontium-90, plutonium-239, and americium-241.*

To date, Sellafield has handled more than 25,000 tons of spent fuel (a mix of civilian and military material). The theoretical annual capacity is 1,500 tons, and up to 1,100 tons of spent Magnox fuel is in storage at any one time—awaiting reprocessing. In the mid-1970s, Sellafield released about 200,000 Curies per year into the Irish Sea. In 1984, this had been decreased to 45,000 Curies.

The Irish Sea

The Irish Sea is taken to extend from the Mull of Galloway to a line from St. David's Head to Carnsore Point (Figure 1). A series of depressions forms an axial trough extending the whole length of the Irish Sea from north to south, roughly parallel to the Irish Coast, and lying 20 to 30 miles from it. The trough contains a number of closed sedimentary basins.

It is flushed almost wholly by Atlantic Ocean water that enters from the south through St. George's Channel. There is a counterclockwise gyral circulation within the Irish Sea, a very small and probably sporadic return flow southward out of St. George's Channel, and some variability in the distribution of outflow water northward into the Scottish Coastal Current. Nevertheless, the mean circulation patterns of the Irish Sea are relatively simple and constant (Figure 5).

The discharges from Sellafield into the Irish Sea fall generally into two components, the soluble and the non-soluble. The distribution of the soluble water-borne radionuclides is illustrated by cesium-137 (Figure 6), while the distribution of the non-soluble, largely sediment-bound, fraction is illustrated by plutonium-239/-240 (Figure 7).

The soluble radionuclides in the discharges have an Irish Sea residence time of about two years. They then are moved northward through the North Channel, around Scotland, and into the North Sea. Residence times in the North Sea increase from north to south, from a few months to less than two years. Dilution in the main Sellafield plume between the Irish Sea outflow and the North Sea inflow, though variable over the short-term, is estimated to average a factor of three. The available data convincingly demonstrate that the flow around Scotland into the North Sea is the major pathway for the dispersion of nuclide-labelled water leaving the Irish Sea. The radionuclide-bearing waters are in turn discharged

* Cesium-134 and ruthenium-106 are not particularly long-lived, relative to the others, with half-lives of 2 years and 1 year, respectively.

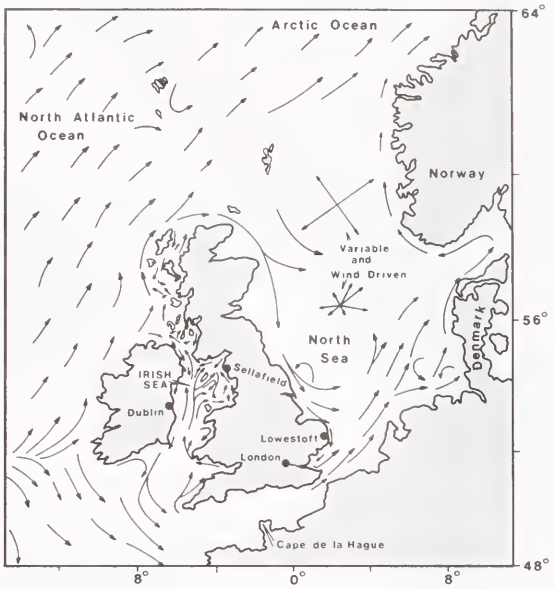


Figure 5. Surface circulation patterns in the vicinity of the discharged nuclear fuel reprocessing wastes to the Irish Sea. The location of the Fisheries Research Laboratory in Lowestoft, responsible for studies of radioactivity in surface and coastal waters of the British Isles, is also shown. (After Livingston and others, J. Mar. Res. *40*(1): 259)

The Hanford Discharges

Britain was not the first to discharge radioactive wastes to the sea. The first deliberate introduction of anthropogenic radioactivity into the ocean was via the Columbia River when nuclides were added to the river at the Hanford Reservation near Richland, Washington, 360 miles upstream from the mouth of the river.

Beginning in the 1940s, thousands of Curies of low-level nuclides were discharged through the cooling water of Hanford's reactor plants. Unlike present nuclear power reactors where the primary coolant is contained in a closed system, the Hanford plutonium production reactors were cooled by water that passed through the reactors and was then discharged into the Columbia River. Nine reactors were built at Hanford; during full operation (from 1955 to 1964) about 1,000 Curies per day were deposited directly into the Columbia. The first plutonium-producing reactor at Hanford began operations in 1944, and the last reactor to be cooled by river water was shut down in January 1971.

The results of the investigations by independent academic researchers concluded that the discharge from the Columbia River into the North Pacific Ocean at the rate of about 1,000 Curies per day did not affect marine organisms or jeopardize the health of man.

—Source: NACOA 1984 Report, p. 91

Figure 6. The concentration, in picoCuries per liter, of cesium-137 in seawater of the Irish Sea; (A) July 1973, (B) January 1976, (C) May 1978, and (D) November 1984. Radiocesium values in the Irish Sea peaked in the mid-1970s and have decreased since. (Redrawn with permission from D. F. Jefferies and others, 1982, Deep-sea Research *29*(6A): 724–725; *and G. J. Hunt, 1985,* MAFF Aquatic Environment Monitoring Report No. 13)

from the North Sea to the Norwegian Coastal Current. While there are measurable quantities of the Sellafield effluent in the North Atlantic surface circulation, according to Hugh D. Livingston, Senior Research Specialist at the Woods Hole Oceanographic Institution, most of the release appears to be headed toward, or is already resident in, the sub-Arctic seas and the Arctic Ocean.

The sediments of the Irish Sea have become the sink for the non-soluble components of the Sellafield discharges. This component tends to adsorb strongly onto particulate matter, and is carried to the seabed, where it accumulates. As a result, such nuclides as plutonium, americium, and ruthenium are mostly immobilized in the sediments near to the discharge point, within approximately 30 kilometers. It is known, for example, that more than 90 percent of the plutonium discharged from Sellafield appears to reside in these sediments, and some sediments are contaminated with up to 105 picoCuries per gram of plutonium-239/-240 (this is about 3 orders of magnitude greater than what would be considered normal background levels). R. J. Pentreath and others (see Selected References) report that at least 6,500 Curies of plutonium-239/-240 and 7,800 Curies of americium-241 are associated with the seabed in a coastal strip 30 kilometers wide in the vicinity of Sellafield. (According to Livingston, typical "background" levels, due primarily to bomb fallout, in an area of 1,000 square kilometers of coastal marine sediment at this latitude, would be about 2 Curies of plutonium-239/-240 and about 0.5 Curies of americium-241.)

The sediment sink, however, is neither perfect nor permanent. The Environment Committee stated, "that radionuclides arrive back on land is confirmed in research." The pathways to man from this source appear to be via two principal directions: indirectly through shellfish, and directly through contact with resuspended sediments. Results reported by the Environment Committee show that the dominant radioactivity in shellfish is attributable to ruthenium-106, and that concentrations in the vicinity of Sellafield are high as compared with other areas. As an example, the mean radioactivity of winkles (small, edible, sea snails) taken from the Sellafield shoreline was 486,000 picoCuries per kilogram, compared to 2,000 picoCuries per kilogram in samples from other areas around the British Isles.

A second mechanism for return is through the resuspension of sediment (storms and local hydrography), which results in some accumulation of radioactive muds in estuaries and salt marshes on the nearby coasts. In general, it is the fine-grained muds and silts prevalent in estuaries and harbors, rather than the coarser-grained sands on the beaches, which adsorb the radioactivity. Radiation exposure via this sediment pathway may be generalized exposure (gamma radiation); direct—from contact with muds or fishing gear; or through ingestion and inhalation—of silts exposed at low tide, dried, and subsequently airborne. These factors are taken into account when calculating the radiation exposure of local

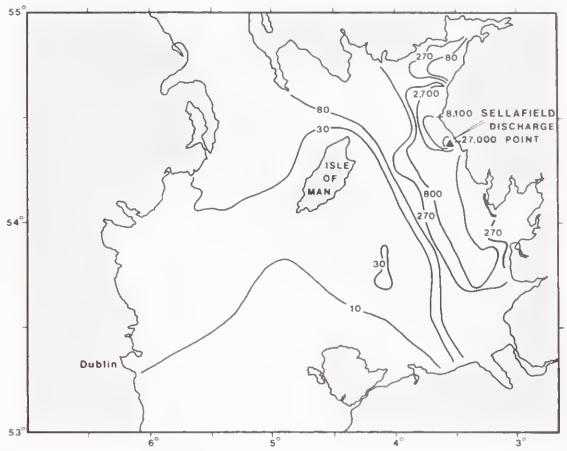


Figure 7. Estimated quantities, in picoCuries per square meter, of plutonium-239/-240 lying within the top 30 centimeters of the Irish Sea sediments as of 1977/78. (Redrawn with permission from R. J. Pentreath and others, 1986)

fishermen who regularly work on the mud-flats.

In general, the Committee viewed the radionuclide-bearing sediments as the most significant pathway to man. Moreover, they state, "the environment around Sellafield has effectively become an open store of long-lived radioactivity," and that due to, "especially the alpha-emitters. . . the Irish Sea will be a source of radiochemical pollution for many years to come." There may be additional difficulties in the sediments. *New Scientist* on February 27, 1986, reported that, "were operations to end at Sellafield tomorrow, the radioactive pollution of the Irish Sea would continue to increase. Some nuclear waste decays into radionuclides which are more dangerous, biologically, than their parent compound. Plutonium-241 as discharged from the Sellafield pipeline is a low-energy beta emitter. But, it decays fairly rapidly to form americium-241, a high-energy alpha emitter. By the end of the next century, it is calculated that alpha emissions will be appearing in the Irish Sea at a rate which is greater than the alpha discharge limit of the Sellafield Plant before 1970."

Lastly, it appears that some of these radionuclides are not restricted to the sediments. Several recent studies reported by Livingston and others have indicated that small but significant concentrations of plutonium and americium do not adsorb to the sediments, but rather move with the soluble nuclides dispersed in the circulating water.

Bioaccumulation and Critical Pathways

Results have shown that "dilute and disperse" works only imperfectly for the sea discharge of liquid radioactive wastes. Although all mechanisms and pathways are far from being known, radionuclides have been shown to return to land and ultimately to the human environment. Several examples are illustrative.

One of the early pathways to man involved

Radiation and Human Health

The relationship between low-level radiation and human health is, at present, unclear. The concern, of course, is that radiation leads to cancers and genetic defects. But, conclusions about the effects of low-level radiation on human health are based on an array of facts that include radiation science, risk estimates, and statistical analyses.

Although there is a good deal of uncertainty, the current literature reports general agreement on several points:

- *Cells most affected by radiation are those that are rapidly dividing, such as blood and blood-forming (bone marrow), basil skin layers, intestinal lining, and in males, germ cells. Data also suggest that the embryo, fetus, and young child are relatively susceptible to carcinogenic effects of radiation.*
- *Just as bioaccumulation occurs in marine organisms used as food, bioaccumulation likewise occurs in human tissue. Radionuclides are known to accumulate in the intestine, thyroid, muscles, bone, and other organs and tissues.*
- *There is no threshold level of radiation. That is, there is no level of radiation exposure that is without effect.*
- *Under normal circumstances, more than 95 percent of the radiation a person receives is a total of natural (from cosmic rays and naturally-radioactive materials on and in the earth), and medical (from X-rays, radioisotopes, and other radiation treatments). Less than 1 percent is from man-made nuclear releases.*
- *Radiation-induced cancers and genetic effects have no distinguishing features by which they can be recognized, and, they often do not appear until years or decades after the irradiation. Further, similar cancers and mutations often occur in the absence of any radiation, natural or man-made, and are attributable to other causes.*
- *Statistics used to infer probabilities of childhood cancers and other radiation effects have sometimes been misused. Statistical inference is at its most robust with high incidence rates, large sample sizes, and long time scales. It is least reliable at low incidence rates, small sample sizes, and short time scales.*

The overall view is accurately reflected in the conclusions of the Environment Committee on this topic. After reviewing its evidence, the Committee stated, ". . . so far, there is no proof to show that discharges have caused adverse health effects to humans." In the face of uncertainty, however, it, like many others, recommended a reduction in discharges. It also noted, "throughout its history, the nuclear industry's discharge limits have had to be continually revised downwards as more knowledge about health effects has become available, and this is good reason to be at least cautious rather than dismissive in our approach."

—Catherine L. Colby

the seaweed, *Porphyra umbilicalis*, a seaweed harvested and used in the preparation of a Welsh delicacy called laverbread. In the vicinity of Sellafield, *Porphyra* accumulated 10 times the concentration of cesium-137, and 1,500 times the concentration of ruthenium-106 found in the water. Despite the high concentrations of radioactive materials in these algae, they were unaffected by them. Surveys carried out in South Wales (where almost all the consumption took place) showed that 26,000 people consumed up to 75 grams per day of laverbread regularly. A small group of 170 adults, however, had individual consumption rates of about 160–388 grams per day. Of the variety of radionuclides concentrated by *Porphyra*, the most important was ruthenium-106, which accumulates in the lower large intestine. Calculations based on conservative assumptions showed that the critical sub-group was receiving between 25 to 50 percent of the maximum recommended annual dose limit (set by the International Commission on Radiological Protection (ICRP)) via this pathway. In the mid-1970s, *Porphyra* ceased to be a significant pathway when it was no longer used in the preparation of laverbread.

Fish and shellfish next emerged as the critical pathway to man. In this case, the dominant radioactivity in fish is attributable to cesium-137. Locally-caught fish assumed a critical position. In 1976, the critical group among members of the public received 25 percent of the ICRP-recommended dose of cesium-137 from this source. In subsequent years, the figure was reduced to about 10 percent of the limit, as discharges were reduced and preventive measures were enacted.

In shellfish, the dominant radioactivity is from ruthenium-106 and other non-soluble radionuclides.* In 1982, new surveys by the

* Naturally-occurring radionuclides also are concentrated within the marine food chain. For example, P. McDonald and others (*J. Environ. Radioactivity* 3: 293–303, 1986) report that mussels in the vicinity of Sellafield, as well as

Nuclear reactors operating and under construction as of 1981—565 nuclear reactors for generating electric power in 39 countries. (Courtesy Rockefeller Foundation Illustrated 5: 8–9, 1981)

Ministry of Agriculture, Fisheries, and Food (MAFF) revealed that the estimated consumption by the critical group of consumers had increased threefold, and that their intake of plutonium and americium had increased by a similar factor. It had also been discovered that the uptake of plutonium from food by the human gut is five times higher than was formerly thought. The dose of plutonium received by the critical group was thus increased by a factor of 15, bringing their total exposure to 39 percent of the ICRP annual dose limit. Subsequently, steps are now being taken to further reduce the discharges of alpha-radioactivity.

An Improving Trend

Since the high discharge levels of the 1970s, there had been a substantial investment by BNFL aimed at reducing discharges. As a result, discharges to the sea from Sellafield have been progressively reduced during the last 10 years. In general, 1984 discharges were 1/10 of the 1974 levels. A cable from John G. Shaughnessy of the BNFL Information Services Department reports that, "discharges, which in 1984 had amounted to 11 percent of the authorized limit for beta and 6 percent for alpha, were halved in 1985. These levels are scheduled to be substantially further reduced to near zero progressively over the next few years."

BNFL and MAFF monitoring programs likewise report that radioactivity levels in the waters of the Irish Sea have been declining in the past 6 to 8 years. However, while the water-borne radioactivity is decreasing both due to the reduction in discharges and the flushing from the Irish Sea, the sediments in the vicinity of Sellafield remain both a repository and a source of radioactivity.

The Global View

While the Sellafield discharges are primarily a regional issue, on the broader scale, they, like most discharges or inputs, are also a global issue. As regional discharges disperse, they become trans-boundary in nature, and subsequently constitute a portion, large or small, of the total capacity of the world oceans. These policy issues are addressed in *Oceanus*, Vol. 24, No. 1.

On both the regional and the global level, cumulative effects are being considered. While individual and isolated inputs to a large, but finite ocean may, in themselves, be inconsequential, a continuing accumulation of radioactive waste is occurring. The approximately 360 nuclear detonations by the United States, the Soviet Union, Britain, France, and China are estimated to have input about 55 million Curies of radioactive cesium and strontium into the oceans. Several hundred million Curies of tritium (radioactive hydrogen) have been input from these same explosions. This fallout is the largest source of anthropogenic (man-produced) radioactivity in the ocean.

Accidental input also occurs. On January 21, 1968, a B-52 U.S. aircraft crashed near Thule, Greenland, depositing plutonium isotopes onto the ice and into the sea. On April 10, 1963, the U.S. nuclear submarine *USS Thresher* sank off the New England coast. The *USS Scorpion* sank in late May,

from remote British and French coastal sites, concentrate naturally-occurring pollonium-210, an alpha-emitter with a half-life of 138 days. The levels may equal or exceed those due to plutonium and americium from localized discharges, and may be a major contributor to human radiation exposure in some instances.

1968, off the Azores. The U.S. Navy has estimated that about 30,000 Curies remain in the reactor compartments of each submarine—they will be released to the environment when the submarines deteriorate. In 1964, a satellite nuclear power generator from a failed satellite re-entering the atmosphere deposited about 17,000 Curies of plutonium-238 into the atmosphere.* On land, a major accident was the explosion of a Soviet nuclear waste dump at Kyshtym in the Ural Mountains in 1957. Perhaps the worst U.S. commercial nuclear accident was the partial core meltdown at the Three Mile Island reactor in Middletown, Pennsylvania, on March 28, 1979. The most recent major incident has been the Chernobyl reactor fire, near Kiev, on April 25, 1986.

Conclusions

Near the end of its report, the Environment Committee states, "It may prove in centuries to come that we have been over-cautious; that the low levels really are not significant; and, that the health consequences are negligible. Conversely, the reverse may be true; and the releases, of even very small amounts of long-lived and dangerous radionuclides into our environment today, will prove to be seriously harmful in a hundred years time, when it will be too late."

* The waste discharges at Sellafield represent a small fraction of the total man-made contribution. The single event of the nuclear satellite power source alone deposited about 12,000 Curies of plutonium-238 into the ocean, while the Sellafield discharge during the 21-year period, 1957 to 1978, amounted to 14,000 Curies of plutonium-239/-240.

Looking to the future, there can be little doubt that alternate energy sources (alternate to fossil fuels) will be not only desirable, but required. If nuclear power is to be one of those sources, and used sensibly and safely, then radioactive waste management is essential. Britain, among others, has taken a leadership role. The checks and balances between government, industry, citizens, scientists, and environmental groups, however, has been shown to be important, both throughout the world, and on the shores of the Irish Sea.

James H. W. Hain is Assistant Editor of Oceanus, published by the Woods Hole Oceanographic Institution.

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A Radiation Primer

A review of some chemistry may be helpful to the understanding of nuclear radiation. All atoms are composed of a central, heavy, nucleus orbited by a "cloud" of electrons. The nucleus is composed of protons and neutrons. The number of protons defines the chemical characteristics of an atom, and hence of any element composed of these atoms. This number is the atomic number. The number of electrons in an atom equals the number of protons, but the number of neutrons may vary. These variants, known as isotopes, have the same chemical properties, but differ in nuclear mass. For example, the atomic number of uranium is 92, but there are several isotopes. In nature 99 percent of uranium occurs as uranium-238, while 0.7 percent occurs as the isotope uranium-235 (the only naturally-occurring fissionable material), which has 143 instead of 146 neutrons in the nucleus. Because of fewer neutrons in the nucleus of uranium-235, it is unstable. To approach stability, atoms seek to alter the proton/neutron ratio, and in so doing, emit particles and energy. These emissions are radioactivity, and the unstable emitting isotope forms are radioisotopes or radionuclides. As the emissions progress, and the isotope approaches stability, the composition of the nucleus changes, and the isotope decays, often in stages, to eventually arrive at a different but stable isotope. The final (stable) decay product, for example, from uranium-238 (after passing through several intermediate stages) is lead-206.

Each radioisotope has its characteristic form of emissions. The radiated emissions are in the form of particles and/or electromagnetic radiation. The three principal types of radiation emitted by radioisotopes have a characteristic form and properties:

- alpha radiation—the largest particle emitted during radioactive decay, consists of a heavy chunk of the nucleus, comprising two neutrons and two protons. However, because of its mass, it has low penetrating power, and is stopped by paper or a thin layer of tissue (less than 0.013 centimeters). It is intensely ionizing, however, and can cause more damage to tissue than other radiation types. Alpha radiation is of biological consequence primarily if taken into the body by ingestion or inhalation.

- beta radiation—consists of electrons. It varies widely in energy level, and has moderate penetrating power (can be stopped by 40 millimeters of tissue). Like alpha particles, their biological significance is greatest if a beta-emitter is taken into the body, although beta penetration can be deep enough to constitute some danger from decay of nuclides on the ground or on the skin (producing skin burns).

- gamma radiation—a form of electromagnetic radiation, similar to X-rays. It has high penetrating power (lead shielding required), can pass easily through matter and tissue, and while less intensely ionizing than other forms, because of penetrating power, can irradiate the whole body. Both alpha and beta emitters, especially the latter, may also emit gamma radiation.

The rate at which these unstable atoms will disintegrate or decay is often stated as half-life, or the time in which one half of the atoms will decay. Each radioisotope decays with a specific half-life. For example, the half-life of uranium-238 is 4.5 billion years, while that of iodine-131 is 8 days. There are several units applied to measuring the rate of release of alpha and/or beta particles. One is the Curie (Ci), defined as 37 billion disintegrations per second. Since this is a high level, a commonly-used smaller unit is the picoCurie (pCi), at -1×10^{12} (one trillionth) of a Curie. The emission so measured can be of one type (alpha or beta), or a mixture of both. Since the level of radioactivity is more significant than the mass of the material, it is common to express the total amount of the substance in terms of the number of Curies it contains. Since radioactivity (Curies) is inversely related to half-life, a substance with a short half-life will be intensely radioactive, while one with a long half-life will display lower radioactivity. The volatile iodine-131, for example, has a short half-life, but is intensely radioactive. Given equal radioactivity, however, 1,000 Curies of iodine-131 will exist for a short period, while 1,000 Curies of plutonium will be present in the environment for a long, long, time. Finally, since, in addition, plutonium is an alpha-emitter (intensely ionizing to human tissue), it is regarded as one of the most toxic radionuclides known.

An aquarium's extensive collection of marine animals, such as the sharks, salmon, striped bass, and other open-ocean fishes in this tank, forms a researcher's paradise. (Photo courtesy of Monterey Bay Aquarium)

Research Plays Key Role in Growth of U.S. Aquariums

by Eleanore D. Scavotto

The sea is always the same
and yet the sea always changes.
—Carl Sandberg

Unbeknown to many visitors who walk through the front doors, behind the colorful display tanks of many aquariums are active and important research programs. Aquariums in the United States—presently multiplying at an exotic rate—possess vast potential for research with their wide varieties of aquatic life and water systems that can imitate many coastal environments. These controlled ecosystems and the laboratory space and research equipment of many large aquariums provide opportunities for scientific studies not open to most universities and research laboratories.

Aquatic research in aquariums helps scientists understand natural environments by permitting experiments where physical and biological variables can be changed at will. Controlled environments are easily manipulated, yet retain much of the complexity of the real system, and thereby are more easily studied than the natural marine environment. Expertise of aquarium staff in water quality control and husbandry also offers many opportunities for research—often for problem solving in animal care, water treatment, and disease.

Aquariums have common goals to promote

Biochemical studies of the coelacanth, Latimeria chalumnae, *a rare "living fossil" fish, contribute to the knowledge of fish evolution. (Photo courtesy of the Steinhart Aquarium)*

awareness and understanding of the marine environment through education and research, each of which they stress in different degrees. A complete review of those institutions with research programs is not possible here because of limited space; but by going behind the exhibit tanks of some of the larger aquariums, we can learn how scientific projects add to our knowledge of the aquatic environment.

The Steinhart Aquarium

The Steinhart Aquarium in San Francisco, California, has used aquatic animals for research since it opened in 1923. The Aquarium, a division of the California Academy of Sciences, conducts research on object discrimination by dolphins,* the behavior and biochemistry of bioluminescent fishes, the adaptation of deep-sea fishes, and the breeding of many invertebrates and fishes, among other programs. Staff and visiting scientists use the vast water systems to imitate various aquatic environments for controlled experimental studies. In conjunction with the California Department of Fish and Game, aquarists and herpetologists are trying to breed several rare and endangered species in captivity and then release them when they mature.

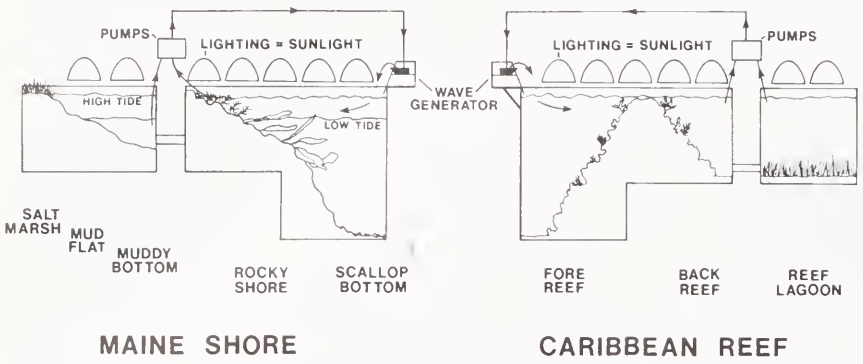
Steinhart's expeditions to exotic aquatic outposts, such as the Amazon, and the Comoro Islands in the Indian Ocean, have yielded rare specimens for study, including freshwater dolphins and flashlight fishes. The Aquarium has studied the behavior and bacterial symbiosis of several flashlight fish species, including *Photoblepharon palpebratus, Anomalops katoptron,* and *Kryptophanaron alfredi.* In addition, biochemical studies of the frozen tissues of the coelacanth—the rare "living fossil" fish—have contributed to the knowledge of fish evolution.

The department of Aquatic Research at the California Academy of Sciences was created in 1982 to encourage expanded use of the Steinhart Aquarium by biologists. The department's research tends to be behavioral and physiological rather than systematic. Current projects include studies of the growth and buoyancy control of the chambered nautilus, responses of sharks to weak electric fields, anaphylaxis in fish, continued studies of coelacanth anatomy and physiology, the breeding behavior of Jackass penguins, and the symbol-discrimination abilities of Pacific white-sided dolphins. John E. McCosker, Director of the Steinhart Aquarium and Curator of Aquatic Biology, focuses his research on studies of the behavior of the great white shark, the systematics and evolution of tropical eels, the relationships of bioluminescent fishes and their symbiotic bacteria, and the evolution of the Galápagos fish assemblage.

Research associates and other outside scientists, supported by grants or by their home

Current research at the Steinhart Aquarium includes studies of the growth and buoyancy control of the chambered nautilus (Nautilus pompilius). *(Photo courtesy of the Steinhart Aquarium)*

* The names dolphin and porpoise are often used interchangeably: dolphin is a Greek word, while porpoise is the Roman name for the same animal. Researchers who separate dolphins and porpoises recognize dolphins as those small cetaceans with a long beak and conical-shaped teeth (family *Delphinidae*) and porpoises as small cetaceans with no beak and spatular-shaped teeth (family *Phocoenidae*).



The Smithsonian's marine ecosystems simulate the functions of the shallow water Caribbean coral reef and the Maine coastal waters. (Drawing done by Charlotte Johnson)

institutions, and Academy staff conduct research. In the future, the department hopes to hire some of its own researchers and to expand the laboratory space currently available for scientific work. Other future research, according to McCosker, includes continued white shark research with the intent of keeping a specimen alive in the aquarium for behavioral and physiological study, husbandry of striped bass with the intent of replenishing depleted stock, and the fabrication of a living shallow water Pacific coral reef for public display and research.

The Smithsonian's Marine Microcosms

The Smithsonian's Marine Systems Laboratory (MSL) at the Museum of Natural History in Washington, D.C., uses Caribbean Reef and Maine coast microcosms as manipulative models for the study of animal behavior, the relationship between algal turf community structure and nutrient levels in both environments, studies of wave action and current flow, and other research. The microcosms closely simulate the functions of the shallow water Caribbean coral reef and the Maine coastal waters, respectively, providing a means of comparing the two types of ecosystems as well as controlled and natural environments. The microcosms are used for applied as well as basic research.

Collecting plants and animals for the microcosms, which are designed not just to look lifelike, but to be lifelike, demanded a different strategy from that usually followed by aquarium scientists. The microcosms were developed not by attending to the needs of individual organisms, but by supporting the physical and chemical needs, and general patterns of energy exchange, that typify either ecosystem. Both ecosystems are almost self-sufficient: their water requires no changing or special chemical treatment, and their animals feed themselves; only a minimal amount of outside food is supplied. Algal scrubbers add oxygen and remove animal waste and carbon dioxide much as the ocean would. Each microcosm has two interconnected tanks that recreate their natural physical and biological characteristics. Constant, automatic monitoring of salinity, oxygen, acidity, and nutrients ensures that these parameters stay close to their natural levels.

The reef, opened in 1980, currently contains 300 different species of algae, fish, coral, and other invertebrates. The shape and community structure of the reef have been scaled after a typical eastern Caribbean reef, as have the light, wave energy, and current conditions. Research includes work on the production rates of algae in conjunction with light conditions and wave action. According to Jill Johnson, Chief Technician of the MSL, from what has been learned about algae production, and growing algae on artificial substrates in the microcosm scrubbers, the MSL is raising a Caribbean King Crab, *Spinosissimus*, in the Caribbean; the crabs are growing on algae on screens on floating rafts. Nutrient levels of nitrogen and phosphorus also are studied in the reef microcosm.

After 20 years of research in Atlantic subarctic-coastal waters, Smithsonian scientists made a model of a realistic, representative ecosystem from that region. With funding from Chevron USA and the National Oceanic and Atmospheric Administration, the scientists enlarged the exhibit and opened the Maine coast microcosm to the public in June of 1985. With 50 to 100 species, current research involves kelp production and invertebrate grazing behavior. MSL scientists have worked in the field on an improved method of mussel mariculture that grows kelp on floating rafts along with the mussels. Walter Adey, Director of the Marine Systems Laboratory and curator of paleobiology at the Natural History Museum, said the ecosystem's most important contribution may be to marine ecology.

Monterey Bay Aquarium

Research at the Monterey Bay Aquarium in Monterey, California, focuses on the regional marine habitats of central California. Present studies deal with the ecology, behavior, physiology, and natural history of local organisms. Open since October 1984, the Aquarium also conducts studies related to the maintenance and health of species on display. Research is overseen by a Research Advisory Committee, which includes prominent scientists from other marine research institutions on Monterey Bay.

The primary goal of the research program, the major portion of which the aquarium is still planning,

The study of how physical and biological disturbances affect the biological structure of kelp forests is a long-term research project at the Monterey Bay Aquarium. (Photo courtesy of Monterey Bay Aquarium)

will be to establish a broad, multidisciplinary study of the Monterey Bay region, with initial focus on the Monterey submarine canyon. The principal emphasis will be on the biology and ecology of resident organisms, with secondary emphasis on physical oceanography, marine chemistry, biochemistry, and geology as they relate to biological problems. According to James M. Watanabe, Research

Biologist, the Aquarium is searching for a director for its research program and hopes to have a better idea of where it is going with the program within the next few years.

Research projects fall into three catgories, the first two of which are already instituted. The first, in-house research, includes monitoring the growth and development of biological communities within the exhibit tanks and developing techniques for treating and controlling diseases, and for maintaining various organisms that have been traditionally difficult to keep. The second is basic research: two field projects, both long term, are now under way. Scientists study the population biology of tagged sea otters in the Monterey Bay area by collecting data on the movements, foraging patterns, and reproductive behavior. The other project is a study of local kelp forests and how physical and biological disturbances affect their biological structure. Deep-sea research, the third category, will focus on the Monterey Submarine Canyon and deep water habitats of central Calfornia. This research is still in the planning stage.

Mystic Marinelife Aquarium

Mystic Marinelife Aquarium, located in Mystic, Connecticut, is a division of Sea Research Foundation, Inc., and like most aquariums is dedicated to education and research. Staff members and adjunct scientists have run a research program in several disciplines, including marine mammal biology, husbandry, and medicine since the institution opened in October 1973. Some of the aquarium's contributions to the science of marine mammalogy are the development of techniques for acclimatizing adult northern fur seals to captivity, the first successful hand-rearing of orphaned seal twins, and the development of a chemical method for estimating maximum allowable ammonia concentration in saline water. These contributions and others impact such areas as fishery resources management, fish biology, aquaculture, and water quality maintenance.

The number and scope of research projects undertaken at Mystic Marinelife Aquarium increases annually. Projects for 1985 included studies on chlorophyll chemistry, growth rates, and nutrient requirements of three species of oceanic phytoplankton; the development of methods to rear brine shrimp to adult size in batch culture for application in aquaculture; changes in the chemistry and bacteriology of seawater used to transport fishes; continuing work on enumeration and isolation of bacteria and yeasts found on wild, beach-stranded, and captive marine mammals; the study of teeth of beluga whales, and other projects.

Since most research at the Mystic Marinelife Aquarium is opportunistic, a schedule of 1986 research programs is not yet available, but would probably include the 1985 projects, many of which are ongoing. Ground breaking for a Whale Study Center, to be dedicated to the rescue, rehabilitation, and research of sick and injured marine mammals, is targeted for the Spring of 1988.

Proposed Aquariums

Bill Sargent, Director of the Coastlines Project in Woods Hole, Massachusetts, said that about 24 major aquariums are presently in the planning stage in America and Canada, as many cities follow the impetus of waterfront renewal that has been sparked by such aquariums as the New England Aquarium in Boston, Massachusetts, and the National Aquarium in Baltimore, Maryland.

According to Quenton Dokken, Executive Director of the Texas State Aquarium Project, and Christopher Roosevelt, head of a group in Stamford, Connecticut, working on the proposed Norwalk Maritime Center, aquariums have been proposed in New Orleans, Louisiana; Clearwater, Florida; Denver, Colorado; Philadelphia, Pennsylvania; St. Louis, Missouri; Portland, Maine; Charleston, South Carolina; Toronto, Canada; and several other cities.

The planned Texas State Aquarium, in Corpus Christi, Texas, for example, with a targeted opening date of Spring 1991, will develop research programs with various universities. Aquarium staff will study marine ecology, animal physiology, and biology. Graduate students in marine science and other related fields will use the aquarium for thesis research. Universities across the state will conduct cooperative research projects. The Corpus Christi Aquarium Organization is a nonprofit group of private citizens who will help create the aquarium and act as its managing entity when it opens. Forty percent of the required funds have already been raised, and another major fund raising effort started this past summer.

The proposed Norwalk Maritime Center in Norwalk, Connecticut, will be mostly educational with spinoff research in conjunction with various universities—the University of Connecticut, Yale University, Columbia University, and others. A public laboratory and a laboratory area for more specific research groups will encourage a broad spectrum of academic research. With a planned opening date of April 1988, the half-aquarium, half-maritime center will accept research fellows with funding and be a place where graduate and doctorial candidates, and post-doctoral fellows can use the facilities to develop research projects. The science program will be based on existing research and education programs of the Oceanic Society. The center will have a 40-foot research vessel with ocean and marine biological equipment for both the aquarium's own and visiting researchers.

Limited Research Programs

While most aquariums, both existing and proposed, plan to or already participate in scientific studies, research programs generally evolve as the aquariums themselves grow. Thus, recently opened aquariums, such as the National Aquarium in Baltimore, Maryland, and The Living Seas in Orlando, Florida, are still implementing research, a process that often takes years.

Nancy Hotchkiss, Assistant Director of Public Programs said the National Aquarium is interested in research, but currently that is not its major focus. The Aquarium, only five years old, is still establishing

Mass strandings of marine animals, such as whales, provide research opportunities through necropsies. (Photo courtesy of New England Aquarium)

its collection. A research program is evolving, and the aquarium is in the process of planning an expansion with space for a separate research laboratory. The primary research done so far is through the Department of Veterinary Medicine. Other than water quality testing, quarantine, medicine and day-to-day operations, no major research currently is being done beyond the short-term study of observations of new animals. By intensifying certain conditions and observing the animals' behavior, researchers can focus on adaptation.

Robert Jenkins, Director of the Husbandry and Operations Department, said that to date, most of the research has been empirical: as an interesting situation develops, it is studied. Research in husbandry and medical areas hopes to allow the aquarium to improve how animals are kept, such as through disease prevention. Medical studies of bacteria in sharks and fish immune systems will contribute to this aim. The costs of research are hidden in the normal operation budgets, but equal about a fifth of the total operating budget.

Another aquarium that presently has a limited research program is The Living Seas at the Epcot Center in Orlando. Tom Hopkins, Marine Mammal Curator, said that research at The Living Seas, only open since January 1986, is still developing. Two types of behind-the-tanks research currently involve studies of ozone levels and vocalization of dolphins. Scientists are studying the effects of changes in the ozone level to the water systems. Dolphin vocal behaviors are being studied. In a conventional aquarium situation, a trainer gives a signal, and the dolphin responds with a given behavior. Here, a computer that records and analyzes specific sounds will allow the dolphins to exert some control over their own environment. For example, every time a dolphin emits a given sound, even if that sound in nature connotes hunger, a trainer will throw a ball in the water (or some other action). By reinforcing, or linking, a dolphin-produced sound to a trainer response or environmental change, the dolphin can communicate in a limited way. In this manner, researchers can study dolphin behavior.

Seabase Alpha, The Living Seas Underwater Research facility designed to explore man's deep-rooted relationship to the oceans, allows visitors to view many experiments conducted by research divers. Future research includes training divers to monitor the condition of reefs, testing manufacturers' diving gear (research and development), and developing remotely operated vehicles (ROVs).

Aquariums with Research Institutions

An aquarium's extensive collection of living and preserved aquatic animals and birds, including many rare and endangered species, form a researcher's paradise. In the carefully designed environments, the animals' behaviors afford opportunities for meticulous scientific observation. Thus, it is not surprising that research institutions are adjacent to some of the larger aquariums. New England

American Aquariums*

Ak-Sar-Ben Aquarium
Route 1
Gretna, NE 68028

Aqualand
Route 3
Bar Harbor, ME 04609

Aquarium of Niagara Falls
701 Whirlpool St.
Niagara Falls, NY 14301
Research Fields: Water quality; dietary supplements; marine mammal husbandry, and skin properties.

Belle Isle Zoo & Aquarium
Box 39
Royal Oak, MI 48068

The Cleveland Aquarium
E. 72nd St. & Interstate 90
Upper Gordon Park, OH 44103

Dallas Aquarium
Box 26193
Dallas, TX 75226

Depoe Bay Aquarium
Box 89
Depoe Bay, OR 97341

Discovery Place
301 N. Tryon St.
Charlotte, NC 28202
Research Fields: entomology; ichthyology; history of technology.

Gavins Point National Fish Hatchery Aquarium
Rt 1, Box 293
Yankton, SD 57078

The Living Seas
Epcot Center
Orlando, FL 32830

Marineland, Inc.
Box 937
Rancho Palos Verdes, CA 90274

Marineland, Inc.
Route #1, Box 122
St. Augustine, FL 32084
Research Fields: specimen health and maintenance.

Marine Systems Laboratory
Museum of Natural History
Smithsonian Institution
Washington, D.C. 20560

Marine World Africa USA
Marine World Parkway
Vallejo, CA 94589
Research Fields: dolphin communication; sea lion gestural comprehension; sea lion breeding; river otter reproduction; killer whale vocalizations.

Memphis Zoo & Aquarium
2200 Galloway
Memphis, TN 38112

Miami Seaquarium
4400 Rickenbacker Causeway
Miami, FL 33149
Research Fields: study and raising of sea turtle hatchlings; behavioral and nutritional studies concerning Florida manatee husbandry.

Monterey Bay Aquarium
886 Cannery Row
Monterey, CA 93940

Mystic Marinelife Aquarium
Coogan Boulevard
Mystic, CT 06355
Research Fields: marine mammal husbandry; seawater chemistry.

National Aquarium in Baltimore, Inc.
Pier 3, 501 E. Pratt St.
Baltimore, MD 21202

National Marine Fisheries Aquarium
Woods Hole, MA 02543
Research Fields: fisheries research by Northeast Fisheries Center.

New England Aquarium
Edgerton Research Laboratory
Central Wharf
Boston, MA 02110
Research Fields: monitoring of water quality of Boston Harbor; animal husbandry; fish diseases; marine mammals.

New York Aquarium
West 8th St & Surf Ave
Brooklyn, NY 11224
Research Fields: all aspects of aquatic animal biology; fish genetics.

Oceana—Marinelife Center
Cedar Point
Sandusky, OH 44870

Point Defiance Zoo & Aquarium
5400 N. Pearl St.
Tacoma, WA 98407

San Antonio Zoo & Aquarium
3903 North St. Mary's St.
San Antonio, TX 78212

Sea-Arama Marine World
Box 3068
Galveston, TX 77550
Research Fields: ridley sea turtles; sharks.

Sea Life Park
Makapuu Point
Waimanalo, HI 96795

Sea World, Inc.
1720 South Shores Drive
Hubbs-Sea World Research Institute
1700 South Shores Road
San Diego, CA 92109
Research Fields: marine science.

Sea World of Florida
7007 Sea World Drive
Orlando, FL 32821

Sea World of Ohio
1100 Sea World Dr.
Aurora, OH 44202

Sealand of Cape Cod, Inc.
Route 6A
Brewster, MA 02631

Seattle Aquarium
Pier 59, Waterfront Park
Seattle, WA 98101
Research Fields: biological fields relating to marine life.

John G. Shedd Aquarium
1200 South Lake Shore Drive
Chicago, IL 60605
Research Fields: marine and fresh water fish; zoology.

Steinhart Aquarium
Golden Gate Park
San Francisco, CA 94118

T. Wayland Vaughan Aquarium
Scripps Institute of Oceanography
University of California
La Jolla, CA 92093
Research Fields: fish diseases; pigmentation; aquariology.

Waikiki Aquarium
2777 Kalakaua Avenue
Honolulu, HI 96815
Research Fields: ecology of shark species; age determination and growth rate studies; reproductive activities of *Exallias brevis*; larval fish research; discovery of new species of *Holacanthus*; Nautilus tracking; biology of giant clam.

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* Compiled from the American Association of Zoological Parks and Aquariums' list of aquariums and the 1986 edition of The Official Museum Directory's listings of research fields. Not all research fields are listed.

Aquarium, in Boston, Massachusetts, and Sea World in San Diego, California, have made research such a big part of their programs that both feature research institutions.

The New England Aquarium conducts research through its stranding programs and the Edgerton Research Laboratory. The Aquarium, along with Sealand of Cape Cod and the College of the Atlantic in Bar Harbor, Maine, handles strandings of beached mammals in Massachusetts, Maine, and New Hampshire as participants in the Northeast Regional Stranding Network. The Aquarium is searching for answers to the mystery of strandings through a combination of laboratory research and behavioral studies of live animals at sea. The new Animal Care Center, part of the Marine Mammal Rescue Program, enables the aquarium to handle the annual influx of orphaned seals, as well as stranded whales and dolphins or sick aquarium animals. Strandings provide information on animals otherwise unobtainable (see *Oceanus*, Vol. 21, No. 2, p. 38).

Aquarium staff work with distressed and injured mammals doing systematic analyses of tissue samples and collected data. Necropsies—autopsies performed on dead animals—yield data on the natural history of the animals and can provide clues to the cause of death. Scientists measure the animal, determine its age by tooth counts, check stomach contents and parasite loads, and look for significant pathological findings. Live animals often are brought back to the Aquarium for medical evaluation.

Besides strandings, the Edgerton Research Laboratory (ERL) is an integral part of the New England Aquarium, supplying research in the basic and applied sciences. The Aquarium sponsors studies in marine biology/invertebrate zoology, aquatic microbiology/marine biodeterioration, aquatic chemistry, ichthyology/community ecology, and marine mammals. The establishment of the Edgerton Endowment for Research in 1982, with its goal of a million dollars, will enable visiting scientists to conduct aquatic research.

The ERL developed water quality analysis techniques, specifically in Boston Harbor and Massachusetts Bay. Several research projects have centered on physical, chemical, and biological problems surrounding oil drilling operations on George's Bank. Another area of research is the development of captive breeding and aquaculture techniques, and conservation-related studies of threatened and endangered species. Aquarium researchers also have initiated long-term studies of the ecology, reproduction, and behavior of whales in the North Atlantic, particularly the endangered right whale.

Hubbs-Sea World Research Institute in San Diego, California, established in 1963, continues to evolve as a highly productive marine research foundation. Working in the areas of mariculture, conservation, resource management and education, ecology of marine animals and animal behavior, the Institute is located adjacent to Sea World. Sea World, through its parent company, Harcourt Brace Jovanovich, Inc., provides working facilities for the Institute, opens its collection of marine animals for research projects, and encourages its staff to work with Hubbs' scientists on joint field expeditions.

Current research projects, many of which are helping to solve ecological problems, include the enhancement of white sea bass and California halibut sport fisheries through the development of mariculture techniques; studies on Mono Lake, where use of the lake as a Los Angeles water source has caused increased salinity and affected marine organisms and avian populations; and bioacoustic studies, which are expanding our knowledge of animals' vocal dialects. Two of the Institute's more frequent areas of study range from studies of population dynamics to analyses of cetacean echolocation and vocalization capabilities. Other research in physiology and physiological ecology investigate the metabolism of marine mammals and birds during diving, swimming, thermoregulation, and free-ranging energetics. Future research will focus partly on a comparative study of cetacean hydrodynamics and swimming energetics.

The Institute also specializes in polar biology and worldwide studies of whale and dolphin population dynamics. A joint effort of Hubbs, Sea World, and the National Science Foundation concentrated on the field and laboratory analysis of penguins. Research findings are applied to aviculture, mariculture, animal medicine and husbandry. There is a constant two-way flow of information between the pure and applied science programs. For example, advances in husbandry at Sea World that have contributed to successful maintenance of bottlenosed and common dolphins, beluga and killer whales, sharks and clownfish, leopard seals, penguins and other birds, have made it possible to study their behavior and sensory capabilities.

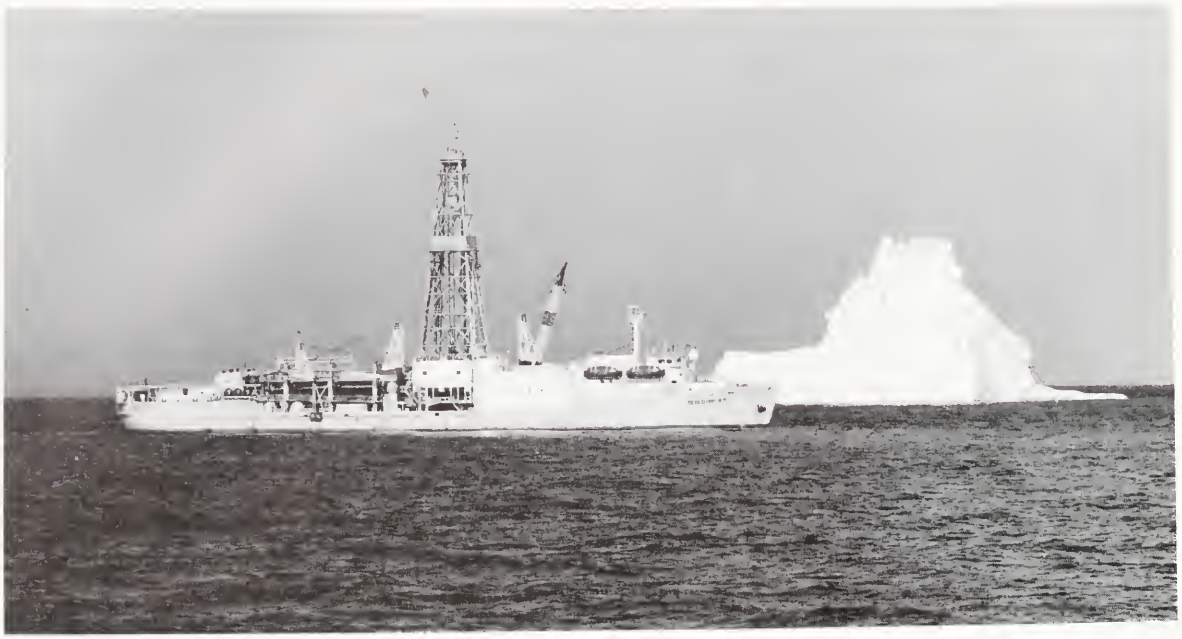
The Institute's primary funding comes from private contributions, a corporate giving program, allocations from an endowment fund, government contracts and grants, and assistance from the Helmsmen, a 120-member volunteer support group. The budget for 1986 is approximately $1 million. Much of the research is contracted by local, state, or federal agencies as part of government's ongoing effort to monitor and protect the marine environment.

Think Tanks, Too

The study of controlled environments that support marine animals and other organisms advances our understanding of the oceans. Aquatic research provides information that can be applied to marine ecology and biology, aquaculture, husbandry, and other areas. Aquariums play a key role in this process through their research and public education programs which provide the knowledge for laws, environmental management decisions, and conservation programs that, in turn, protect oceanic resources. As aquariums continue to open, and research projects continue to develop, more informed decisions can be made to enable us to interact wisely with the ever complex marine ecosystem.

Eleanore D. Scavotto is Editorial Assistant at Oceanus *magazine, published by the Woods Hole Oceanographic Institution.*

Ocean Drilling Program Altering Our Perception of Earth



JOIDES Resolution *drilled in the Labrador Sea and Baffin Bay on Leg 105 where she encountered 38 icebergs. Drilling above the Arctic Circle at the highest latitude and in the deepest water ever drilled by a scientific vessel, the ship retrieved almost one mile of sediment and rock samples from depths up to 3,500 feet (1,147 meters) beneath the seafloor. (All photos courtesy Ocean Drilling Program)*

by Philip Rabinowitz, Sylvia Herrig, and Karen Riedel

With nine internationally staffed scientific voyages completed (as of this writing), *JOIDES Resolution*, mothership of the relatively new Ocean Drilling Program (ODP), appears destined to return results that will alter our perception of Earth. Shipboard analyses of samples, geophysical logs, and implementation of new technology have already made apparent a number of very important contributions to the Earth Sciences.

In some instances, however, it will take many years of detailed analyses to complete the scientific results. For example, Leg 108 off the northwest coast of Africa recovered nearly 4,000 meters of core—the highest recovery in the history of ocean drilling. These cores will help us understand, among other problems, key paleoclimatic responses. But the samples obtained must be investigated in painstaking detail to determine information about the responses which occurred during periods of Earth-orbital changes 20,000 to 100,000 years Before Present (BP).

The Ocean Drilling Program* is operated by Texas A&M University, which is responsible for operating and staffing the *JOIDES Resolution*. The program gives scientists from the international community an opportunity to participate in cruises of approximately eight weeks duration. By examining the cores, scientists can better understand the ages of ocean basins and the processes of their development, the rearrangement of continents, the structure of Earth's interior, and the evolution of life in the oceans, in addition to the history of worldwide climatic changes.

The program is the successor to the Deep Sea Drilling Project (DSDP), which was operated by the Scripps Institution of Oceanography (SIO) of the

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* The U.S. National Science Foundation, Canada, the European Science Foundation Consortium for the Ocean Drilling Program, West Germany, France, Japan, and Britain fund the Ocean Drilling Program. JOIDES (Joint Oceanographic Institutions for Deep Earth Sampling), an international group of scientists, provides overall planning and program advice. JOI, Inc. (Joint Oceanographic Institutions), a nonprofit consortium of 10 major U.S. oceanographic institutions, manages the program. Lamont-Doherty Geological Observatory of Columbia University is responsible for the logging operations.

Crewmen are shown lowering the frame for the television camera which is used to help the ship find a drill site and re-enter a hole.

University of California at San Diego. The drilling vessel *Glomar Challenger* was operated by Scripps between 1968 and 1983. That drill ship logged 375,000 miles, drilled 1,092 holes at 624 sites, and recovered 96 kilometers of core. Throughout the life of the program, major advances were made in the understanding of fundamental Earth processes as well as in ocean technology. As a result of those advances, the Ocean Drilling Program was launched with high expectations—a new 10-year international program of scientific ocean drilling aboard a larger drill ship with expanded laboratory facilities and capabilities of retrieving cores from the remotest regions on Earth.

The Search for a Ship

The search for a new drill ship began in mid-1983 (see *Oceanus*, Vol. 27, No. 4, p. 85). Only a handful of drill ships in the world were capable of meeting the new program's needs. Our mission: to find a drill ship capable of 1) housing a scientific and technical party of 50; 2) operating in high latitudes and rough seas; 3) being converted into a research vessel with fully operational laboratories and an ultra-long drill string; and perhaps most formidable of all, 4) having an affordable price tag.

The search led to *SEDCO BJP 47*, now known to the scientific community as *JOIDES Resolution*. She came to us a 470-foot, dynamically positioned drill ship with a 200-foot derrick and facilities for housing and feeding 110 people for 70 continuous days. We added a seven-story laboratory stack, strengthened the hull, and made room for 30,000 feet of drill string. Her conversion began in late April 1984. Nine months later, we had a floating laboratory with some of the most sophisticated, state-of-the-art scientific and drilling equipment in existence.

Converting the Ship

The changes required to turn a commercial drill ship into a scientific research vessel were numerous: the derrick, top-drive, guide-rail assembly, and new crown and traveling block were installed and reinforced to withstand heavier loads; the position reference system was modified to include capability for long-base line, short-base line, and ultra short-base line systems; the draw works horsepower and braking capacity were increased considerably; the world's largest heave compensator, capable of keeping the drill string stable relative to the seafloor even in very rough seas, was installed; the pipe racker was modified to increase its capacity in order to accommodate a longer drill string; and an iron roughneck was added to the rig floor to increase efficiency and safety by eliminating the need to manually connect pipe sections.

To make the most efficient use of space, we planned the laboratories using a seven-story design. We constructed three levels in place below deck by taking over a part of the casing hold, added three more laboratory levels above the main deck, and connected the entire six-story structure with a stairway and an elevator. On top of the structure, we added a downhole measurements lab which overlooks the drill floor. We installed a library and study area on the fo'c's'le deck, and an under way geophysics lab on the fantail of the ship.

Marine technicians Henrike Groschel, Greg Simmons, and Harry (Skip) Hutton number and label pieces of basalt recovered from the Mediterranean on Leg 107.

The finished product is a laboratory structure that contains the world's largest and most varied array of research equipment in operation at sea. The laboratories provide space and equipment for sedimentology, physical properties, paleomagnetics, paleontology, chemistry, and petrography, as well as dedicated laboratories for a scanning electron microscope and X-ray diffraction/X-ray fluorescence equipment, a borehole instrumentation laboratory, and as mentioned previously, an under way geophysics laboratory. Computer, photographic, and electronics repair facilities, refrigerated core storage, offices, and a scientific library provide critical support for all scientific research activities.

The Shakedown

The inaugural cruise (Leg 100) of the newly-converted ship began in January 1985. During that cruise, all of the drilling systems and scientific laboratories were tested and the scientific and technical crews were trained on the numerous pieces of sophisticated equipment. The dynamic positioning system was tested in hostile sea conditions with winds between 45 and 55 knots and 18- to 20-foot seas. The *JOIDES Resolution* remained stable and held station to within 50 feet (water depth 3,000 feet). Even in these adverse conditions, high quality cores were retrieved. The 18 days of testing and shakedown proved the ship to be ready; all systems performed up to, or exceeded our expectations. After only two days in port, she was ready to begin her mission.

Scientific Mission and Accomplishments

In 1964, the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES)* was formed. JOIDES is a consortium of international** and domestic institutions dedicated to the study of the Earth beneath the ocean. It was this body that called for a Conference on Scientific Ocean Drilling (COSOD), held in Austin, Texas, in November 1981. The conference's primary objective was to outline the scientific merits of a follow-up program to the Deep Sea Drilling Project (DSDP). The scientific objectives of highest priority were the origin and evolution of ocean crust, the tectonic evolution of continental margins, the origin and evolution of marine sedimentary sequences, and the causes of long-term changes in the atmosphere, oceans, cryosphere, biosphere, and magnetic field. To address these problems, the Ocean Drilling Program began an ongoing R&D program to improve tools and drilling systems. The highly successful coring system is one example. The development of a hard-rock spud-in system, which allows scientists to sample rocks from beneath the seafloor in areas of highly fractured rocks with little or no sediment cover, is our most recent development.

At sea, Leg 105 proved to be one of our most environmentally challenging. The *JOIDES Resolution* withstood the rigors of stormy seas and icebergs while drilling in the high latitudes of Baffin Bay and the Labrador Sea. These regions have played an important role in Earth's climate by serving as the corridor for the exchange of water masses between the Arctic and Atlantic Oceans from the Late Cretaceous (approximately 71 million years ago) until the opening of the Norwegian Sea (60 million years ago). The objectives on this cruise were to determine the timing and nature of the tectonic evolution of these two high-latitude basins and to examine the paleoceanographic development of this region. The sediments recovered during Leg 105 have demonstrated that major glaciation began 2.5 million years BP in the Labrador Sea and possibly earlier in Baffin Bay.

We also have made important inroads in our study of passive—or Atlantic-type continental margins. These margins are thought to have been formed by processes associated with the rifting of continental crust and the embryonic emplacement of oceanic crust during the early formation of an ocean basin. On Leg 103, scientists identified several stages of rifting on the Galicia Margin that include 25 million years of episodic faulting and tilting accompanied by subsidence. Of interest here is that the recovered cores have required us to completely reinterpret the seismic stratigraphy of this region.

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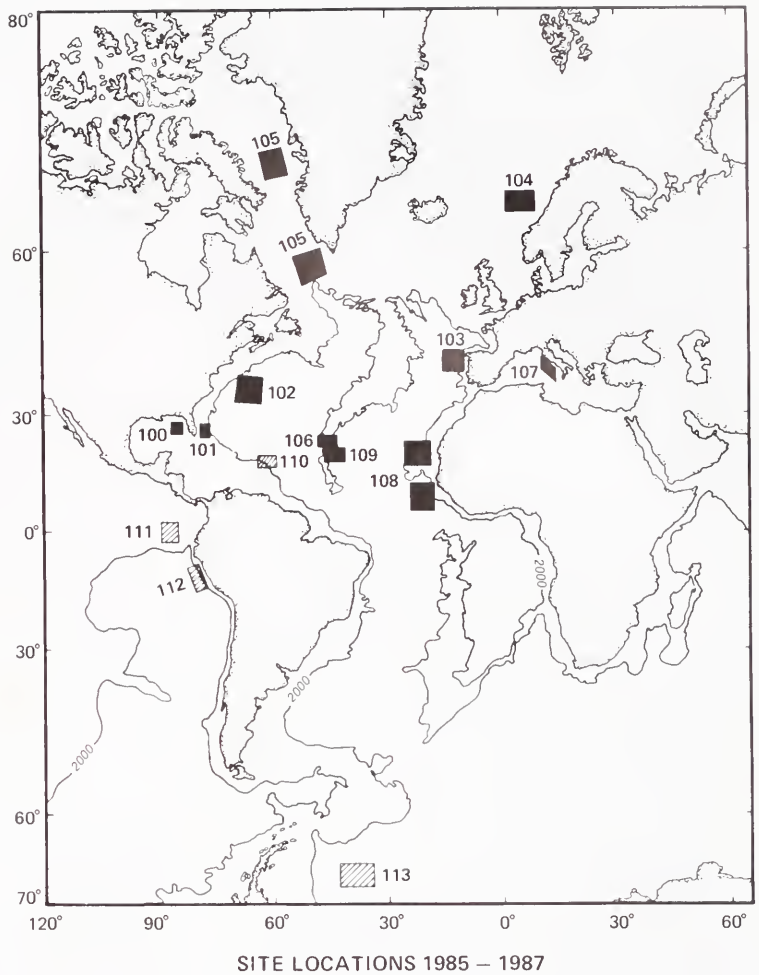
*JOIDES institutions are: University of California at San Diego, Scripps Institution of Oceanography; Columbia University, Lamont-Doherty Geological Observatory; University of Hawaii, Hawaii Institute of Geophysics; University of Miami, Rosenstiel School of Marine and Atmospheric Science; Oregon State University, College of Oceanography; University of Rhode Island, Graduate School of Oceanography; Texas A&M University, Department of Oceanography; University of Texas at Austin, Institute of Geophysics; University of Washington, College of Ocean and Fishery Sciences; and Woods Hole Oceanographic Institution.

** Non-U.S. members are Department of Energy, Mines, and Resources, Earth Sciences Sector, Canada; European Science Foundation Consortium for the Ocean Drilling Program—Belgium, Denmark, Finland, Iceland, Italy, Greece, the Netherlands, Norway, Spain, Sweden, Switzerland and Turkey; Bundesanstalt fur Geowissenschaften und Rohstoffe, West Germany; Institut Français de Recherche pour l'Exploitation de les Mers, France; University of Tokyo, Ocean Research Institute, Japan; and Natural Environment Research Council, Britain.



Ocean Drilling Program site locations 1985–1987. Black blocks indicate sites drilled. Shaded blocks are future sites. (Note: Leg 110 took place June–August 1986).

Sequences of seaward-dipping seismic reflectors of controversial origin have been observed on many borders of Earth's passive continental margins. On Leg 104 off Norway, more than 900 meters were drilled into these seaward-dipping seismic reflectors. The rocks recovered were volcanic and consisted of two series: an upper series of cyclic, subaerially-extruded tholeitic basalt flows with interbedded volcaniclastic sediments and a lower subaqueous, andesitic series related to the rift-to-drift transition. The discovery that these seismic reflectors are volcanic in origin will have a profound influence on our understanding of continental breakup.

One of our principal objectives is to study the nature and evolution of oceanic crust. To date, the program has established two deep (greater than 500 meters subbasement) standard ocean-crustal sections in the Atlantic ocean at formerly-drilled DSDP sites—one in relatively young crust (about 7 million years BP; DSDP site 395) and one in older crust (about 108 million years BP; DSDP site 418). Extensive downhole geophysical experiments were performed. The preliminary interpretations suggest that the older crust becomes sealed by alteration products within the pillow-basalt units in contrast to the younger sites where the upper basalt is relatively porous and permeable.

Perhaps the most exciting endeavor in our exploration of oceanic crust has been the major engineering effort in developing a system to drill very young volcanic rock. Traditional drilling methods into deep-ocean basins depend on thick layers of sediment to provide lateral support for the flexible drill string to penetrate a hard rock surface. Because the ocean floor at the mid-ocean ridge is too young to have accumulated such a sediment, drilling into the newly-formed crust called for a different technique.

During cruises 106 and 109, scientists used a camera similar to the one which helped discover the *Titanic* in 1985 (see *Oceanus*, Vol. 28, No. 4) and were able to view their target—a submarine volcano almost two miles (three kilometers) below the sea surface. A 20-ton guide base was lowered to the seafloor and locked in place with 2,000 cubic feet of cement. The base provided the stability needed to drill and re-enter into the rocky surface. Despite

On the rig floor, the crew removes the 31-foot-long (9.5 meters) core from the core barrel. It is cut into 5-foot sections for analyses.

difficult drilling conditions caused by the hard, fractured volcanic rocks, 50.5 meters were penetrated into the volcanic interior. The technological achievement at the Mid-Atlantic Ridge has provided a permanent undersea laboratory for future studies of the rugged mid-ocean terrain.

The technology employed on Legs 106 and 109 also opened other new opportunities for the scientific community. By using the underwater television camera and by adopting mining technology to the bottom of the drill string, we now have the capability of drilling single-bit holes at selected areas, either sediment-covered or hard-rock seafloor. An exciting scientific result on Leg 106 arose from our capability to drill shallow holes on a transect across a newly discovered, active hydrothermal-vent field in a rift valley of the Mid-Atlantic Ridge. The samples recovered at this exciting location should provide new insight into how sulfide-ore bodies are formed. Further, on Leg 109 our technology has allowed us for the first time to re-enter a hole in more than 3,600 meters of water without the traditional re-entry cone.

Leg 110

This past summer saw the *JOIDES Resolution* drilling in waters off Guadeloupe, Martinique, Barbados, Tobago and Trinidad—known in the Caribbean as the Lesser Antilles. The region has a turbulent geological history.

Stretching from the Virgin Islands at the upper point of the crescent to the islands just off the north coast of Venezuela, the Lesser Antilles is a complex structure known as an island arc in geological terminology. These island groups are found all over the world and typically consist of an arc-shaped chain of volcanic islands bounded by a relatively shallow basin on the concave side and a deep trench and ocean on the convex side.

A series of huge plates carry ocean and continental crust across the Earth's surface. When two plates meet, several events can occur. The Lesser Antilles island arc is an expression of the volcanism created by the North American plate moving westwards and sliding under, or subducting beneath, the Caribbean plate at the rate of about 2 centimeters (almost an inch) a year.

As the North American plate moves under the Caribbean, sediments scraped off the under-thrusting plate are piling up, creating huge masses of crumpled rock and, in some instances, raising some areas above sea level as islands. The process is analogous to shoving your foot into a pile of dirt, accumulating a layer of dirt on top of your shoe. In plate tectonics, the pile transferred from one plate to another is called an accretionary prism. The island of Barbados, on the eastern edge of the Caribbean plate, is one portion of an accretionary prism that has built up above sea level.

The *JOIDES Resolution* drilled into the prism at four sites to recover cores of sediment. Scientists hope to obtain information on the processes associated with active accretionary margins. They are particularly interested in the structural and hydrologic characteristics of the prism formation.

At the base of the Barbados prism is what scientists call a decollement—a detached surface—that in this case separates the over-thrusting prism and the under-thrusting North American plate. Little is known about how these detachment planes develop and what their role is in active accretionary margins. Previous drilling results have shown that this particular decollement contains high-pore pressure and unusually warm fluids which migrate upward. Scientists hope to learn more about the nature of the pore pressure, the source of these high-temperature fluids, and whether or not they are consistent throughout the detachment fault.

This fall, the *JOIDES Resolution* will drill at two sites off the coast of Central and South America. The first site—about 300 miles off the coast of Central America—will be at the deepest hole ever drilled into ocean crust. The ship will deepen the 4,125-foot hole another 1,000 to 1,400 feet. During the last leg of 1986, the ship will drill into the Peruvian margin, where the Pacific plate is sliding underneath South America.

The results gleaned from these cruises will alter our perception of Earth. We are now in a phase where basic Earth processes can be examined, analyzed, and measured more precisely than ever before.

Philip Rabinowitz is Director of the Ocean Drilling Program and Professor of Oceanography at Texas A&M University, College Station, Texas. Sylvia Herrig is the Administrator of the program and Karen Riedel is Coordinator of Public Information.

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SOMETHING NEW UNDER THE SEA

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WAVE & TIDE GAUGE
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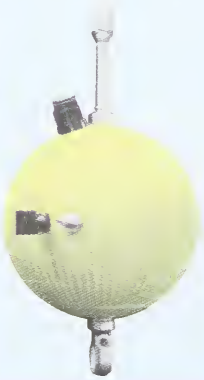
PLUS
Reliable, Economical
Buoys, Releases, Winches

S4 Current Meter

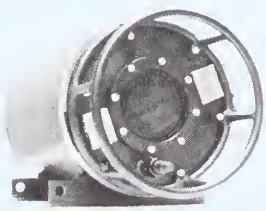
S4D 6000M Current Meter

CTD/S4 Multiparameter Probe



S4P Profiler

WTG/S4 Wave & Tide Gauge



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New Oceanic and Coastal Atlases Focus on Potential EEZ Conflicts

by Charles N. Ehler, Daniel J. Basta, Thomas F. LaPointe, and Maureen A. Warren

Producing atlases of coastal and oceanic areas as a means of providing information for decisionmaking is not a new idea. Since the 16th century—the time of Gerard Mercator—atlases have been used to present new information about the world. During the 17th century, sea atlases printed information previously available only on sea charts for the use of merchants.

Through its *Strategic Assessment Program*, the Ocean Assessments Division of the Office of Oceanography and Marine Assessment, National Oceanic and Atmospheric Administration (NOAA), produces and uses comprehensive data atlases to effectively compile, synthesize, and communicate large amounts of complex technical information on the coastal and oceanic areas of the United States. These atlases use mapped data and other information for national assessments. Our experience indicates that thematic maps can be powerful tools for assessments.

Decisions about the use of coastal and oceanic resources are made constantly in Congress, in state legislatures, in executive agencies at all levels of government, in board rooms, and by individual citizens. They are made over a wide range of spatial and temporal scales, from site-specific decisions to federal policy and programmatic decisions that affect the entire nation—from real-time to long-range. Information of varying types and quality is required for making resource use decisions throughout this range of scales.

NOAA's Strategic Assessment Program

Since 1979, NOAA has been compiling information on important characteristics of the coastal areas and the 200-mile Exclusive Economic Zone (EEZ) of the United States. These data are being organized in the context of a national program of "strategic assessments" of potential conflicts among the multiple uses of resources within these areas. The assessments are characterized as strategic because they develop information appropriate for setting and modifying national objectives to 1) develop and conserve coastal and oceanic resources, 2) identify various means to achieve these objectives, and 3) evaluate the potential effects of their implementation. They are intended to complement, not replace, the detailed "tactical" analyses required to make site-specific decisions.

Strategic Assessment activities bring together four general types of information relevant to decisionmaking: 1) physical and chemical characteristics of resources and their surrounding environment; 2) biological characteristics, including species distribution abundance, life history, and habitat; 3) economic characteristics, including resource extraction and production, marine recreation, and land use; and 4) environmental quality, including pollutant discharges, ambient water quality, and hazardous materials disposal.

One of the most important products of the strategic assessment program is a series of atlases. The atlases serve as the principal vehicles for consistently coalescing and organizing this wide range of information.

Data presented in the atlases are finding increasingly wider applications, ranging from the evaluation of ocean waste disposal strategies, to environmental assessments of major federal activities, such as outer continental shelf oil and gas lease sales, oil spill response, and research planning. Primary users include executives and their technical staffs within NOAA, the Environmental Protection Agency, the Minerals Management Service of the Department of the Interior, the United States Coast Guard, and the Army Corps of Engineers. All are federal agencies responsible for managing human activities that directly or indirectly affect estuarine, coastal, and oceanic environmental quality. Coastal states are a growing collection of users as NOAA's new information and assessment capabilities become better known; congressional staffs, interest groups, and business organizations are also users.

The Atlases

Three distinctly different types of atlases are being developed, each presenting information for different decisionmaking requirements. When completed, the atlases will include more than 700 thematic maps; almost 400 have been developed already.

A series of thematic atlases for the EEZ, the first type of atlas, is the original and still principal thrust of the national program. Four of the most

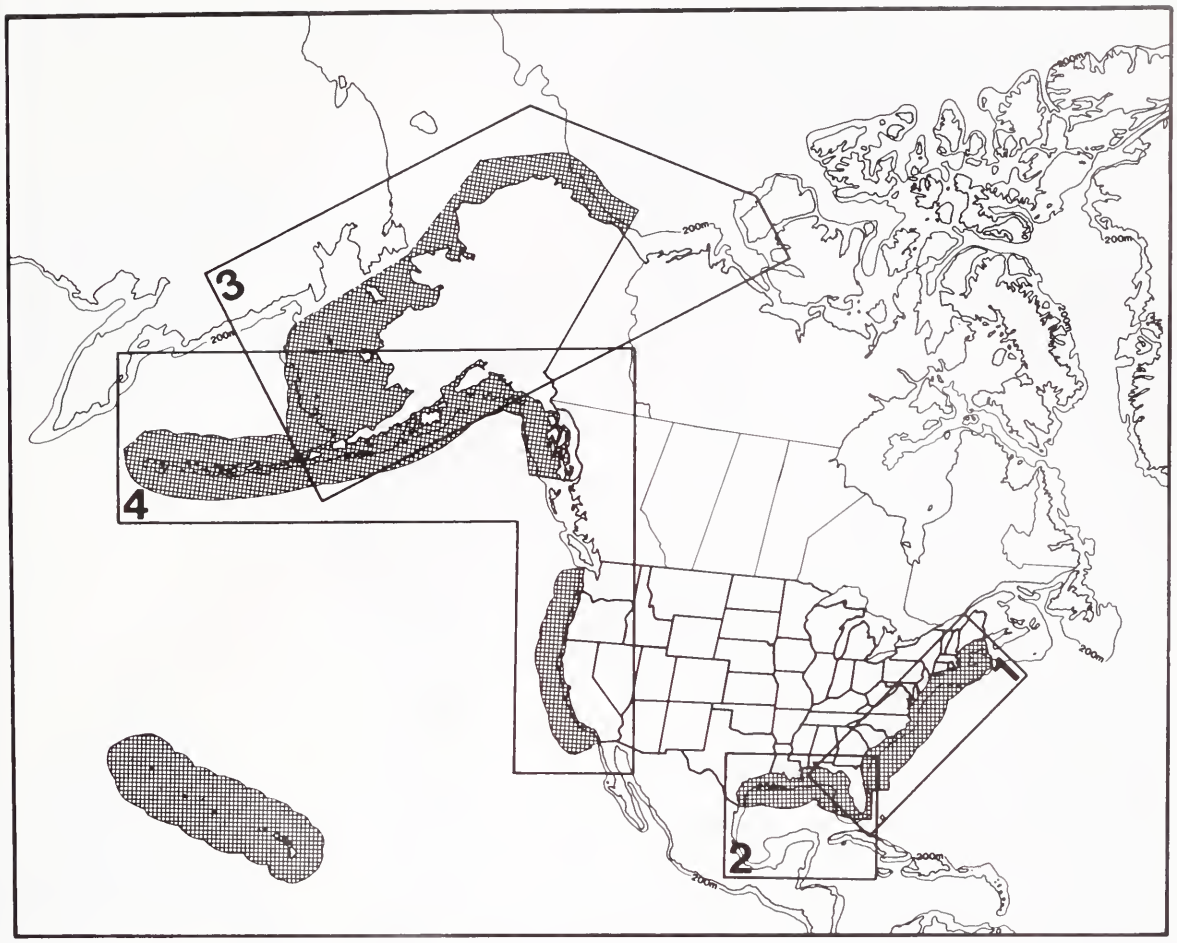


Figure 1. Strategic Assessment Regions of the U.S. Exclusive Economic Zone: 1) East Coast; 2) Gulf of Mexico; 3) Bering, Chukchi, and Beaufort Seas; and 4) West Coast and Gulf of Alaska.

heavily used regions of the EEZ are the principal focus: 1) the East Coast; 2) the Gulf of Mexico; 3) the Bering, Chukchi, and Beaufort Seas; and 4) the West Coast and Gulf of Alaska (Figure 1). A strategic assessment atlas of thematic maps has been or will be produced for each of these regions. Using a consistent format, each atlas brings together for the first time the best available information on important characteristics of each region (see box on page 51).

A second type of atlas is a folio of national maps that presents comprehensive information on the use and health of coastal waters. Its national perspective covers the entire United States on a single page. The general public is its principal audience, and education, its primary purpose.

The third type is an atlas series on estuaries throughout the contiguous United States that aims to present consistent and compatible information on the nation's estuarine resource base. The first volume includes information on the physical and hydrologic characteristics of these areas.

Future volumes will include land use, the distribution and abundance of biological resources, and pollutant discharges. Individual volumes have the format of a workbook that provides information for further scientific and engineering analysis.

Regional EEZ Data Analyses

An *Eastern United States Coastal and Ocean Zones Data Atlas* was published in 1980, following a year and a half of data compilation and organization. It was produced in response to concerns among federal agencies about the environmental quality effects of outer continental shelf oil and gas exploration and production activities, and the location of projected petroleum refineries in adjacent coastal areas of the East Coast. The atlas contains 127 maps of the East Coast, a brief introductory text, and a reference section. A scale of 1:4,000,000 (one inch = approximately 64 miles) was chosen for data presentation to illustrate the spatial extent of natural resources and human activities on a base map covering the entire East Coast.

A *Gulf of Mexico Strategic Assessment Data Atlas* was published by the U.S. Government Printing Office in March, 1986, after about 4 years of data compilation and synthesis. The atlas contains 163 maps of important characteristics of the Gulf of

Mexico, including the Mexican sector (Figure 2).

The quality of the information content and graphic presentation of the Gulf of Mexico data atlas has been significantly improved when compared to the East Coast atlas. Introductory text has been added to each major section and a brief descriptive text written for each map. An extensive "life history table," which summarizes additional information on each species, such as habitat requirements, is included in the "living marine resources" section. This atlas also includes examples of the synoptic capabilities of oceanographic satellites, such as Advanced Very High Resolution Radiometer (AVHRR) sea-surface temperature maps, showing the highly variable nature of the Loop Current in the Gulf of Mexico and chlorophyll-*a* maps of the entire Gulf of Mexico region derived from Coastal Zone Color Scanner (CZCS) data.

A Bering, Chukchi, and Beaufort Seas Strategic Assessment Data Atlas will be printed in early 1987. The atlas will contain 112 maps of the Arctic region, including the Canadian Beaufort Sea and the Soviet Bering and Chukchi seas (Figure 3). A major departure of this atlas from its two predecessors is the emphasis on a relatively extensive description of each map. Special maps developed for the Arctic atlas include sea-ice dynamics and sea-ice type (derived from AVHRR satellite imagery); marine sediments, chlorophyll-*a* (based on Coastal Zone Color Scanner imagery); and subsistence activities of Alaskan Natives, a particularly important human activity in the Arctic, developed from detailed anthropological field surveys conducted by the Alaska Department of Fish and Game.

A *West Coast and Gulf of Alaska Strategic Assessment Data Atlas*, scheduled for publication in early 1988, is the fourth and final atlas in the series on the EEZ. It will contain approximately 150 thematic maps. While the format and content of this atlas is similar to its predecessors, one improvement is the addition of another dimension of oceanic space to the maps. A profile of the vertical distribution in the water column is included for each animal portrayed in the "living marine resource" section (Figure 4).

The Health of Coastal Waters

A folio of 20 maps will be printed in color by the end of 1986, showing the nationwide distribution of human population, municipal sewage treatment plants, fecal coliform bacteria discharges, and areas closed to commerical shellfish harvest, and other indicators of "environmental health." Additional information, such as tidal ranges, coastal circulation, and dredging activities, also will be included.

Each thematic map is accompanied by about 2,000 words of text, plus figures and tables. Atlas pages will be added or updated periodically to include new information generated through ongoing field monitoring programs, such as NOAA's National Status and Trends Program, also managed by the Office of Oceanography and Marine Assessment, which is measuring the ambient concentration of toxic chemicals in mussels and oysters, bottom-feeding fish, and sediments at 150 coastal and estuarine locations.

Figure 2. Sample map from the Gulf of Mexico Data Atlas.

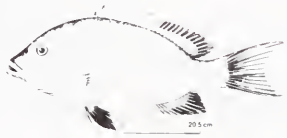
National Estuarine Series

The first atlas in this series was printed in 1985. Mapped and tabular data are presented for the 92 estuaries that account for about 90 percent of the freshwater inflow to coastal waters and 90 percent of the estuarine surface water in the United States. Several small estuarine systems and other coastal

Red snapper

Lutjanus campechanus

Guachinango



Description

Range The red snapper, a bony fish of the family Lutjanidae, is found along the western Atlantic from New England to the Yucatan Peninsula and throughout the Gulf of Mexico. It is particularly abundant on the Campeche Banks, the shelf areas of west Florida, and the northern Gulf.

Habitat These demersal fish are found over sandy and rocky bottoms, around reefs and underwater objects at depths between 0 to 200 meters and possibly beyond 1,200 meters in the northern part of its distribution area; adult red snapper favor deeper waters. Juveniles inhabit shallow nearshore and estuarine waters and are most abundant over sand or mud bottoms.

Feeding and Behavior A common inhabitant of reefs, the red snapper feeds along the bottom on fishes and benthic organisms such as tunicates, crustaceans, and molluscs. Juveniles feed on zooplankton, small fish, crustaceans, and molluscs. The red snapper is a schooling species.

Reproduction Spawning grounds are located in offshore waters and are active from June to October. Juveniles are found in estuaries and inshore coastal areas.

Movement Little movement is shown by tagging studies, except possibly a general offshore movement in cold weather. As juveniles mature, they move into deeper waters.

Fisheries Commercial fishing for this species in the Gulf is more extensive than for any other snapper, with year-round fishery reported off the coasts of western Florida to Texas and off the Yucatan. In terms of landed pounds, the red snapper is the largest component of the snapper fishery. The red snapper is highly esteemed as a recreational sport fish. Recreational fishing grounds are located offshore in the northern Gulf and both coasts of Florida.

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Adult Area (Year-round)

Major Adult Area (Year-round)

Nursery Area (Year-round)

Commercial Fishing Ground (Year-round)

Recreational Fishing Ground (Year-round)

Spawning, from June to October, occurs throughout adult areas.

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Strategic Assessment Branch
Ocean Assessments Division
Office of Oceanography and Marine Assessment
National Ocean Service/NOAA
and the
Southeast Fisheries Center
National Marine Fisheries Service/NOAA

3.36

areas are included because they represent significant coastal features. Data elements include 1) the dimensions and boundaries of estuarine waters and drainage areas; 2) freshwater inflow rates; 3) tidal parameters; 4) stratification classification; and 5) surface area of salinity regimes.

A map of each estuarine system is accompanied by selected vertical cross-sections of the estuary and a table of selected freshwater inflow and tidal data (Figure 5). A second data atlas, containing information on 25 categories of land use within each estuarine drainage area, will be

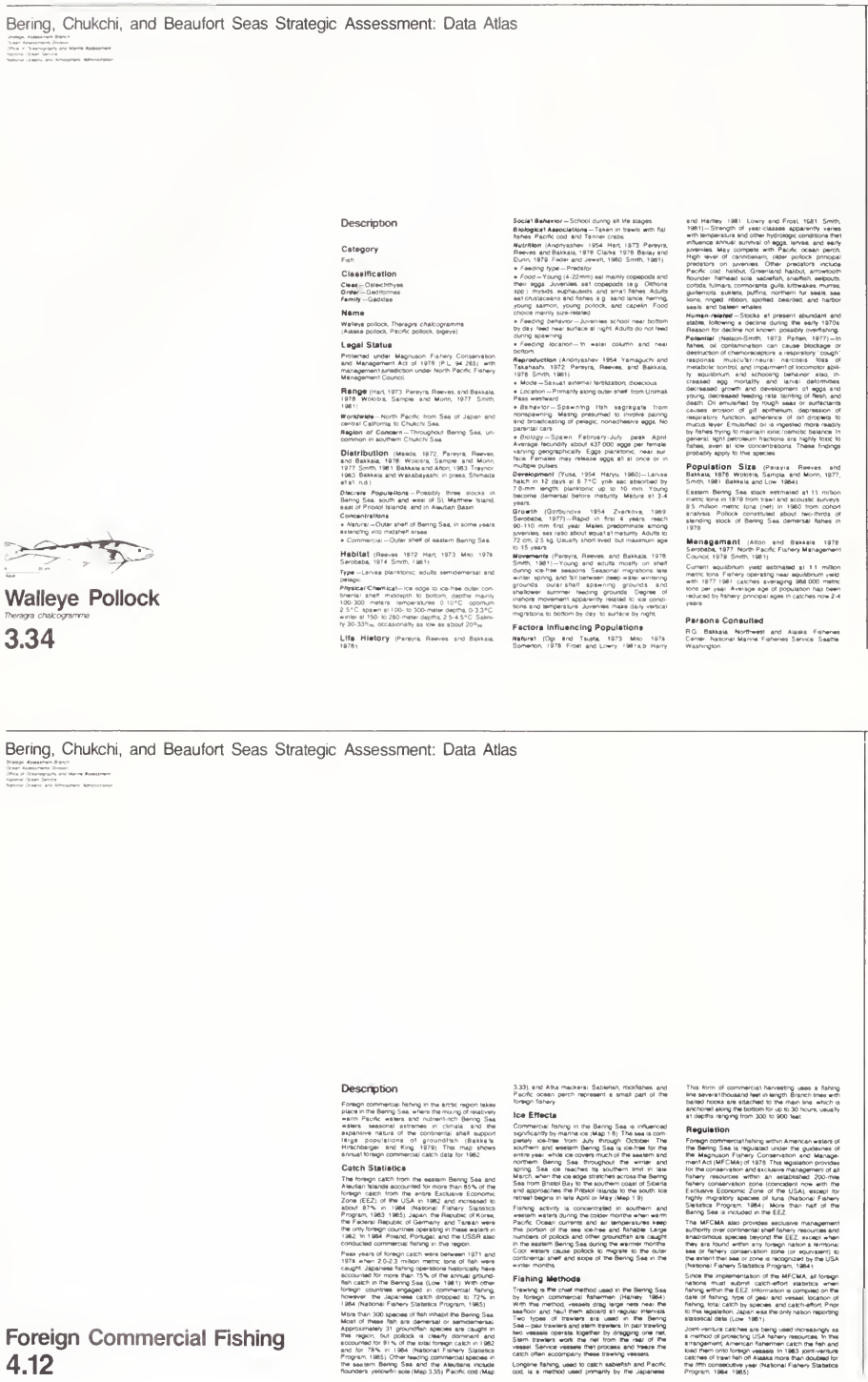
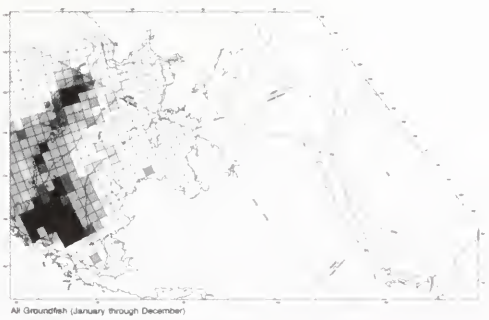


Figure 3. Sample of facing pages from the Bering, Chukchi, and Beaufort Seas Data Atlas.

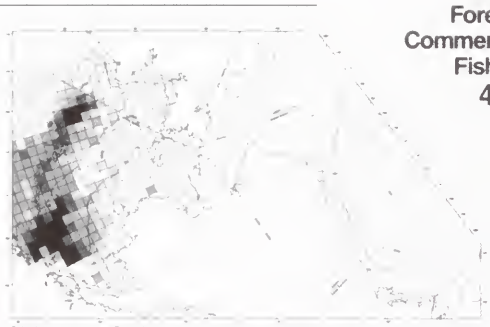
published in 1986. When complete, the National Estuarine Inventory will be used to make comparisons, rankings, statistical correlations, and other analyses related to resource use, environmental quality, and economic values among estuaries.

Although the atlases are a very visible and important part of the Strategic Assessment Program,

Walleye Pollock
Theragra chalcogramma
3.34

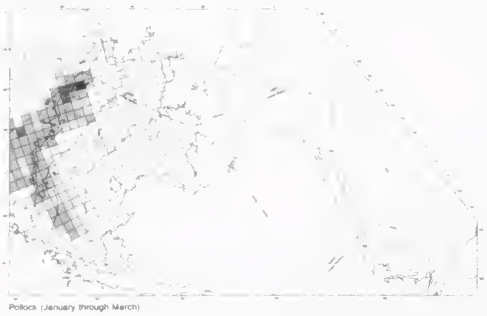


All Groundfish (January through December)



Pollock (January through December)

All Groundfish (January through March)



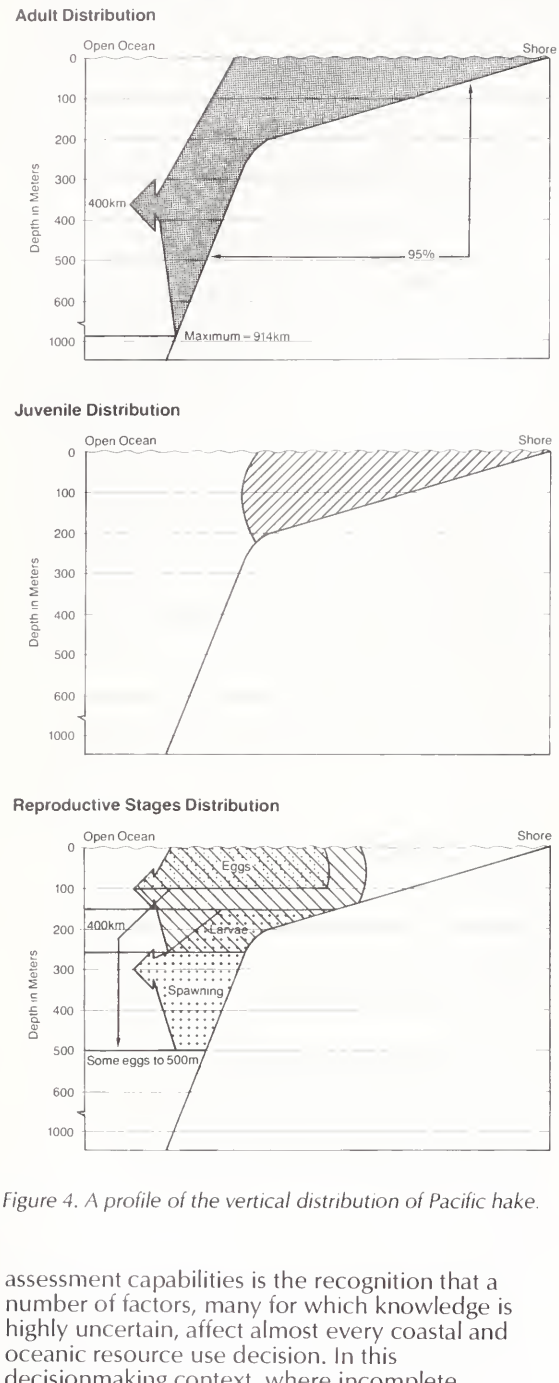
Pollock (January through March)

Foreign Commercial Fishing
4.12

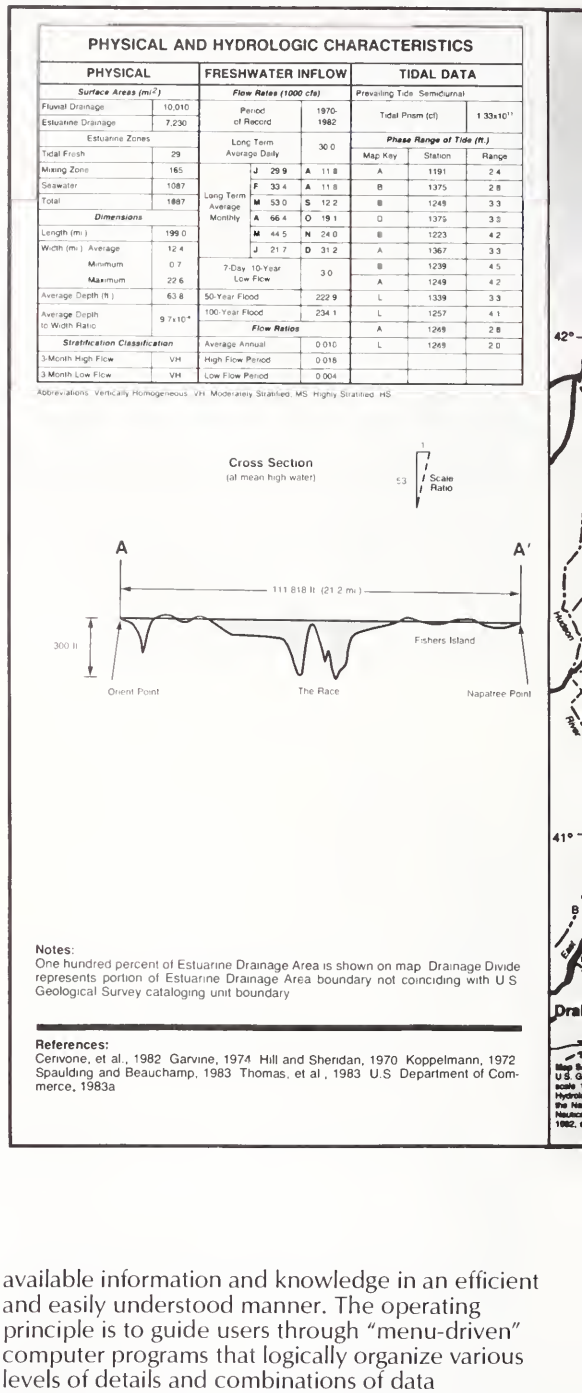
they represent only one step in an evolving process to develop operational capabilities for assessing national coastal and oceanic resource use problems. Another step involves information bases/systems with computer mapping and analysis capabilities.

Computer-Based Mapping Capabilities

A key to developing useful information and practical



National Estuarine Atlas



PHYSICAL AND HYDROLOGIC CHARACTERISTICS

PHYSICAL		FRESHWATER INFLOW				TIDAL DATA		
Surface Areas (mi²)		*Flow Rates (1000 cfs)*				Prevailing Tide Semidiurnal		
Fluvial Drainage	10,010	Period of Record			1970-1982	Tidal Prism (cf)	1.33x10¹¹	
Estuarine Drainage	7,230							
Estuarine Zones		Long Term Average Daily			30.0	*Phase Range of Tide (ft.)*		
Tidal Fresh	29					Map Key	Station	Range
Mixing Zone	165	Long Term Average Monthly	J	29.9	A 11.8	A	1191	2.4
Seawater	1087		F	33.4	A 11.8	B	1375	2.8
Total	1887		M	53.0	S 12.2	B	1249	3.3
Dimensions			A	66.4	O 19.1	D	1375	3.3
Length (mi.)	199.0		M	44.5	N 24.0	B	1223	4.2
Width (mi.) Average	12.4		J	21.7	D 31.2	A	1367	3.3
Minimum	0.7	7-Day 10-Year Low Flow			3.0	B	1239	4.5
Maximum	22.6					A	1249	4.2
Average Depth (ft.)	63.8	50-Year Flood			222.9	L	1339	3.3
Average Depth to Width Ratio	9.7x10⁻⁴	100-Year Flood			234.1	L	1257	4.1
		Flow Ratios				A	1269	2.8
Stratification Classification		Average Annual			0.010	L	1269	2.0
3-Month High Flow	VH	High Flow Period			0.018			
3-Month Low Flow	VH	Low Flow Period			0.004			

Abbreviations: Vertically Homogeneous, VH; Moderately Stratified, MS; Highly Stratified, HS

Cross Section
(at mean high water)

1
53 Scale Ratio

A A'
111 818 ft (21.2 mi.)
300 ft
Fishers Island
Orient Point
The Race
Napatree Point

Notes:
One hundred percent of Estuarine Drainage Area is shown on map. Drainage Divide represents portion of Estuarine Drainage Area boundary not coinciding with U.S. Geological Survey cataloging unit boundary

References:
Cervone, et al., 1982. Garvine, 1974. Hill and Sheridan, 1970. Koppelmann, 1972. Spaulding and Beauchamp, 1983. Thomas, et al., 1983. U.S. Department of Commerce, 1983a

Figure 4. A profile of the vertical distribution of Pacific hake.

assessment capabilities is the recognition that a number of factors, many for which knowledge is highly uncertain, affect almost every coastal and oceanic resource use decision. In this decisionmaking context, where incomplete knowledge and uncertainty exist, assessment capabilities are required that enable the analysis of different assumptions, about both the state of scientific knowledge and alternative management strategies. The new NOAA information bases/systems are designed to apply these capabilities to coastal and oceanic resource use decisions.

An innovative feature of these capabilities is their emphasis on building "expert systems" that use available information and knowledge in an efficient and easily understood manner. The operating principle is to guide users through "menu-driven" computer programs that logically organize various levels of details and combinations of data aggregations and graphic presentations. Another important feature is the emphasis on "audit trail" capability so that the quality of the information itself can be evaluated.

Information mapped in the data atlases illustrates the types of data bases being developed. Each data base is organized geographically so that characteristics can be compared, computer-mapped, and assessed across combinations of spatial units,

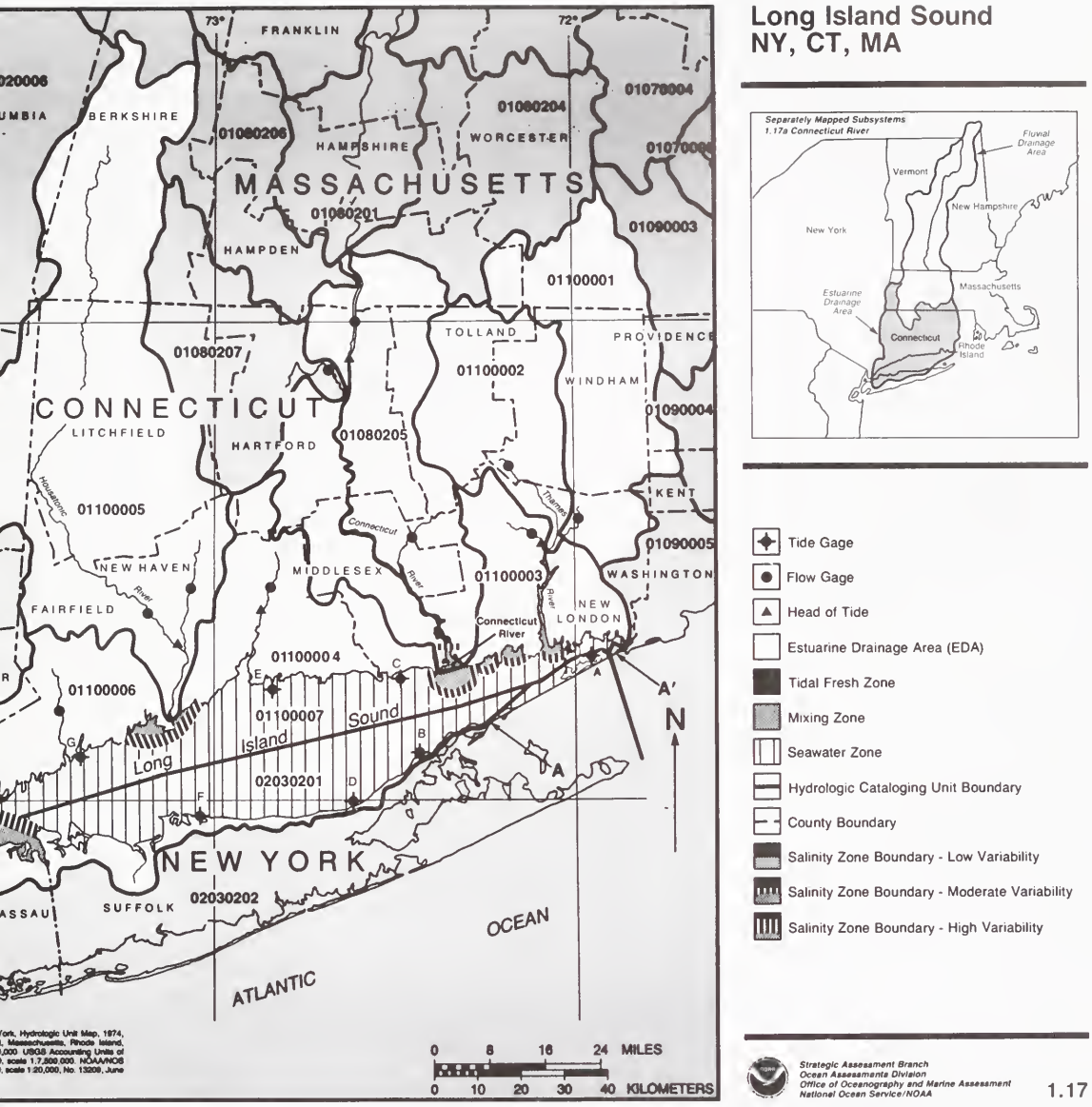


Figure 5. Sample map from the National Estuarine Inventory Data Atlas.

depending on the problem. On land, information is organized by county, urban area, drainage basin, estuary, and in some places, simply by latitude and longitude. The spatial structure of the data bases contains, for example, 316 coastal counties and 92 estuaries throughout the contiguous United States.

Two data bases/assessment systems illustrate the national capabilities being developed. The *National Coastal Pollutant Discharge Inventory* (*NCPDI*) is a data base of discharge from all land- and ocean-based sources of pollution. Since most discharges affecting environmental quality in the EEZ come from land-based sources, information about the nature of these coastal sources is essential. The analytical capability developed through the NCPDI permits the assessment and mapping of the effects of different combinations of economic, technologic, and policy assumptions about the levels and distribution of pollutant discharges. The inventory is being developed to represent conditions during the period from 1980 to 1985. The type of water pollutants considered include 1) oxygen-demanding materials; 2) nutrients; 3) heavy metals; 4) petroleum hydrocarbons; 5) synthetic organics; 6) sludges; and 7) pathogens. Source categories include all point, nonpoint, and riverine sources in coastal and

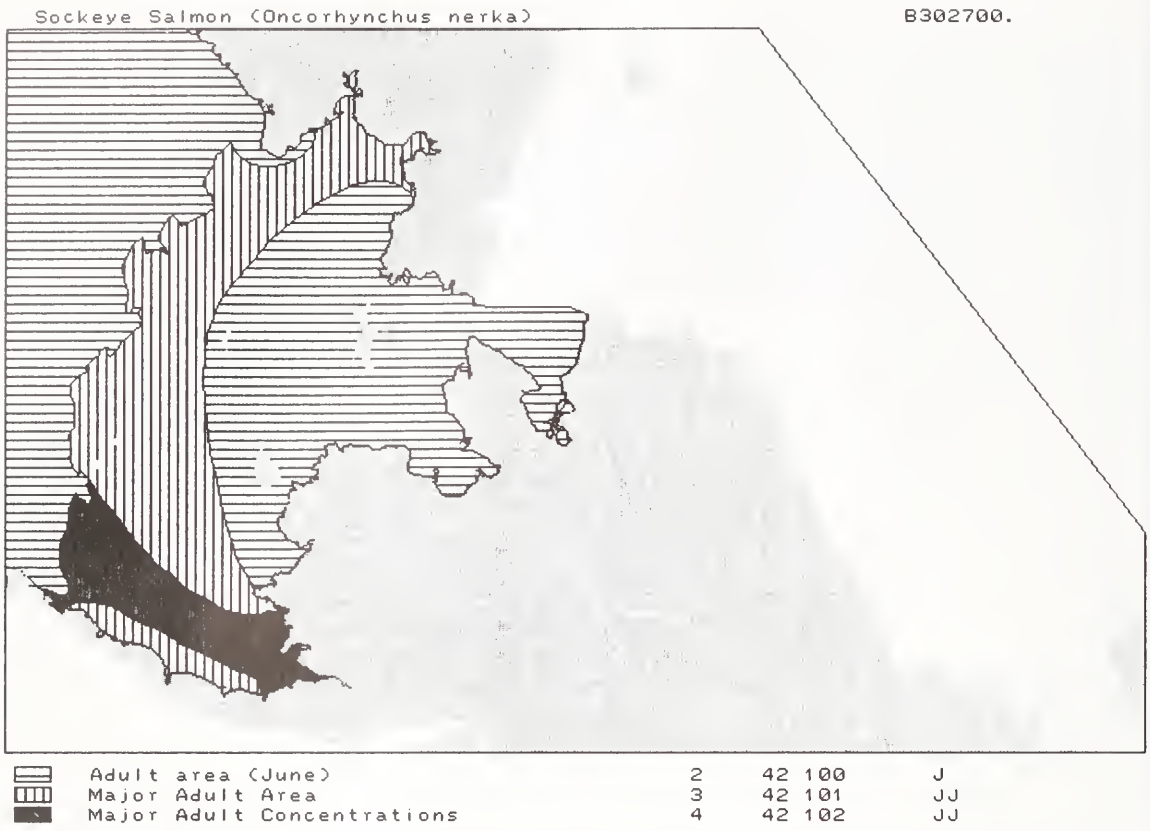


Figure 6. A computer-generated Arctic species map.

oceanic areas.

The *Living Marine Resource Life History Data Base* is a computer mapping and assessment system based on the species distributions mapped in the regional data atlases. Mapping the life history distributions of important living marine resources is a major part of each strategic assessment. This activity is conducted jointly with NOAA's National Marine Fisheries Service. Developing life history maps is the most complex and difficult part of each strategic assessment. As the overall program evolves, so will the content, complexity, and accuracy of information portrayed about living marine resources.

Maps are being developed for more than 300 species of marine invertebrates, fishes, reptiles, birds, and mammals. Each map is a synthesis of existing information (published, unpublished, or computer data bases) on a species that is compiled, assimilated, and evaluated by a team of scientists in each region. Each map portrays the distribution of adults; juveniles; reproduction; routes or corridors of migration; relative abundancies; and areas of commercial, recreational, and subsistence exploitation (Figure 6).

No Shortcuts

The declaration of 200-mile Exclusive Economic Zones by many coastal nations has stimulated new interest in marine resource atlases. In October, 1985, the Challenger Society and the Royal Geographical Society sponsored an international meeting and exhibit in London on marine resource atlases. One of the atlases exhibited was a *Piscatorial Atlas of the North Sea and St. Georges Channels* that had been published in color in 1883, containing 50 maps of fish life history distributions. Before the current NOAA effort, similar marine resource atlases had not been developed for the coastal and oceanic waters of the United States.

This body of information and operational assessment capability have been under development by NOAA for almost seven years. Among the lessons learned is that there are simply no shortcuts to developing these capabilities systematically and carefully. The operational task of integrating data atlases and analytical capabilities is a difficult one, requiring creativity, consistency, and continuity. The process of developing thematic atlases serves as a focal point for codifying consistently what is currently known about important characteristics of the marine environment. The analytical capability to combine, compare, analyze, and map these characteristics comprehensively provides NOAA and other parts of the marine scientific and resource management communities with a basis to organize

The Atlas Preparation Process

While the processes for preparing each type of atlas varies, four activities are applicable to all:

- Designing the Base Map. *The scale of the base map for data presentation is determined by the smallest scale that will allow data presentation on a single atlas page. This criterion is important because the thematic information displayed on the maps, such as the life history of living marine resources, often covers the entire region. A Lambert Conformal Conic projection is generally used to minimize the distortion of geographical features. A standard base map is then compiled from the best available sources.*
- Selecting Data to Map. *National and regional coastal and oceanic resource use decisions usually require some combination of information about 1) physical environments (for instance, wetlands and seagrasses); 2) living marine resources; 3) economic activities; 4) marine environmental quality; and 5) jurisdictions, such as boundaries of maritime zones, state coastal management programs, and federal agency jurisdictions.*

Explicit criteria are used to select and prepare data maps within these categories. The data have to be 1) relevant to the assessment of known or perceived coastal and oceanic resource-use compatibilities or conflicts; 2) geographically comprehensive—cover the entire region with uniform accuracy; 3) reasonably available and accessible within the time constraints of the assessment schedule; and 4) of relatively known quality. Strict adherence to these criteria often leads to significant gaps in mapped data.

- Data Collection and Initial Mapping. *Data for the atlases are collected by and from scientists and analysts throughout NOAA as well as from a wide variety of other sources, including federal, state, and local agencies, universities, other research institutions, private industry, and trade associations. In a few cases, data are compiled and mapped from existing published sources; more often data are collected from unpublished sources and personal communications with various experts, but in many cases, original work must be undertaken to develop data to be mapped. All data sources and quality are thoroughly documented, with typically hundreds of people providing, checking, and validating data.*
- Validation and Final Mapping. *Validation of the working maps is a lengthy, repetitive process. Maps are checked and rechecked, drawn and redrawn, based on source material and consultation with experts both within and outside NOAA. Whenever possible, data and their presentation on atlas maps are checked with the individuals who compiled the original data.The maps generally represent a conservative interpretation of the data. Draft maps are often eliminated because of serious data limitations and others are not included for which even the very best available data raise more questions than they answer.*

and communicate in a timely manner on the effects of alternative policies and actions.

As the products and services of this NOAA program are applied, tested further, and refined, they should provide previously unavailable opportunities for improving the process through which important coastal and oceanic decisions are made.

Charles N. Ehler is the Director of the Office of Oceanography and Marine Assessment, National Ocean Service, NOAA. Daniel J. Basta is the Chief of the Strategic Assessment Branch of the Ocean Assessments Division. Thomas F. LaPointe and Maureen A. Warren are project managers in the Strategic Assessment Branch.

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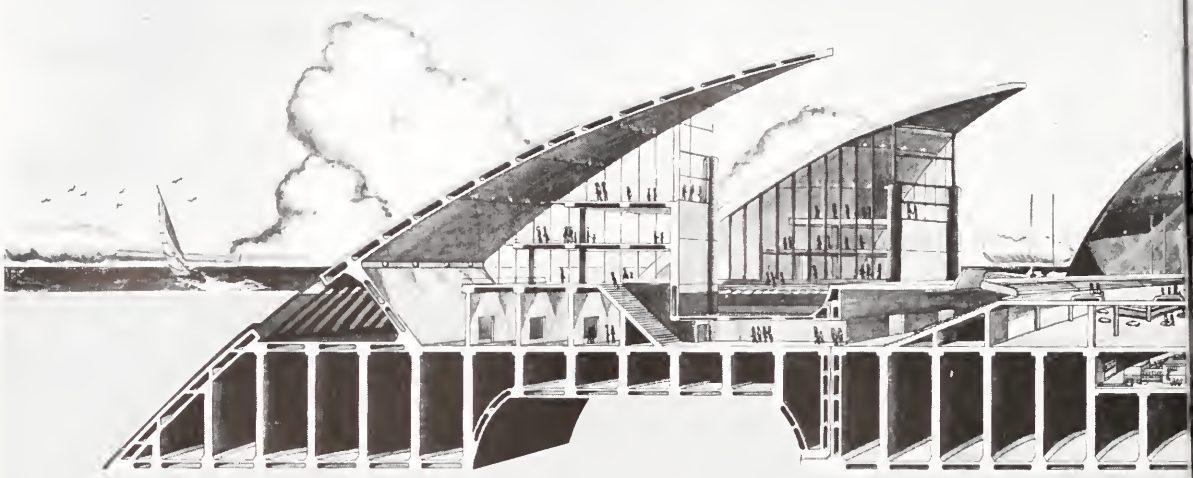


CENTER PLAZA

Oceanic Architecture and

by Paul R. Ryan, and Michael A. Champ

Anything that one man can imagine, another man can realize.
—**Jules Verne**

The Japanese consider ocean space to be a natural resource. Limited in the amount of land usable for future development, they are pioneering a new breed of architect—young Frank Lloyd Wrights of the sea working to meet the severe space demands expected by the middle of the 21st century. Their ambitious dreams—indeed some would say fantasies—include entire ocean cities, some floating or standing on their own sea legs and others resting on man-made islands, as well as modern coastal

Japanese student design for a marine complex (above and below) in a coral reef setting.

断面図

Engineering in Japan

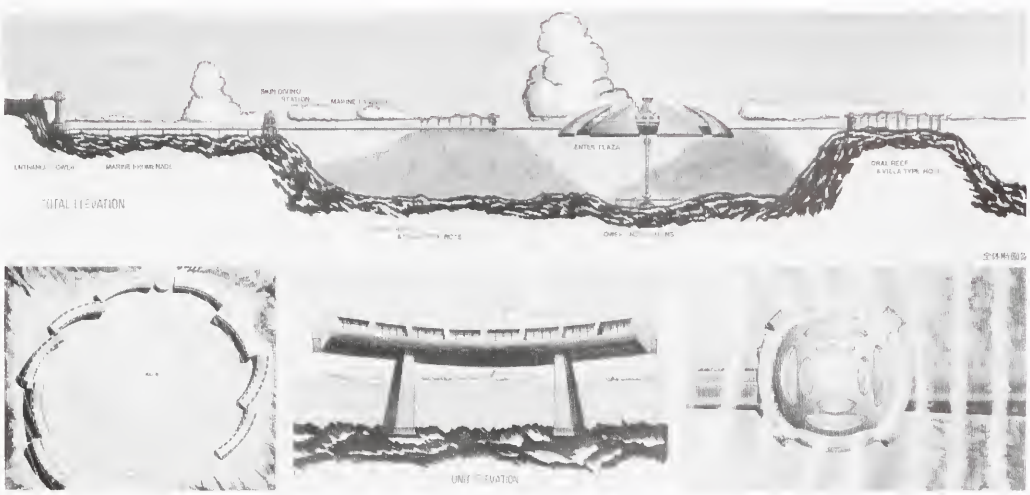


Figure 1. Candidate sites for location of offshore man-made islands.

fishing villages and sites for at-sea energy and chemical plants. There are even concepts for industry that embrace the idea of building textile and other types of plants in foreign waters, such as in India and areas of Southeast Asia, where inexpensive labor-intensive situations exist.

A mountainous island nation, only about 30 percent of Japan's land area (380,000 square kilometers) is habitable, supporting 117 million people. This figure, it is estimated, will reach 140 million by the middle of the next century. Much of the habitable land is also prime agricultural land.

Presently available offshore areas suitable for man-made islands, to water depths of 20 meters, total approximately 7.6 million acres, of which 50 percent is being used in one fashion or another (for mariculture, shipping routes, and so on). In the next two decades it is estimated that the demand for this type of ocean space will exceed supply by about 3.7 million acres (Figure 1). Marine engineers and architects are thus looking to site their projects in deeper water.

Studies by the Ministry of Transport and other Japanese organizations have supported the feasibility of constructing large cities and man-made islands with the aid of advanced technologies from the fields of harbor construction, undersea tunnel construction, long-span bridge construction, offshore structures, and high-volume earth and sand transportation.

The construction of man-made islands in Japan is not new. The practice dates from the early 19th century, when some fortified islands were built in Tokyo Bay for defense. In the 1950s, others were constructed for the mining of undersea coal. In the 1960s, an era of high economic growth, reclaimed land attached to shore was developed for industrial use in various parts of Japan. Emphasis on land reclamation then shifted in the 1970s to man-made islands off the coast as a means of avoiding industrial pollution. The major use to date has been for expanded harbor facilities and airports. Major man-made islands constructed in Japan during the last 20 years and their uses are shown in Table 1.

Japan's ocean architects are thus conceiving plans for new cities at sea, power plants, industrial complexes, educational and research bases, vacation resorts, fishery farming complexes, and a host of other conventional land space uses. In general, there are six structural possibilities for the construction of offshore man-made islands—reclamation, piling, bottom-fixed, jack-up, floating, and semi-submersion (Figure 2). The *reclamation* type of man-made island is constructed by reclaiming the sea area enclosed by revetments* using caissons,** double-wall sheet piles, and other materials. This type of island is vulnerable to strong earthquakes, but resists moderately high waves. In the *piling* concept, a platform is fitted on top of piles driven into the seabed, and structures are built on the platform. This type of structure is affected by earthquakes and wave action. The *bottom-fixed* type of island consists of a structure built on a caisson or a floating body that is towed to the ocean site. This type of island is suitable for relatively shallow water.

A *jack-up* type of island also consists of a structure built on a floating body that is towed to an ocean site. Once at the site, the floating body is jacked up to the appropriate height on legs fixed to the seabed. Many oil rigs in the North Sea use the jack-up principle. Structural weight is restricted by leg strength and jack-up capacity. The *floating* concept requires mooring the structure and is affected by the pitching and rolling caused by waves. However, it is less susceptible to earthquakes. Finally, in the *semi-submersion* type of island, part of the floating-body is submerged to dampen the effect of pitching and rolling. This type of structure was built in Okinawa many years ago to house the World's Fair.

Ocean Communications City

One of the most ambitious projects on the Japanese architectural drafting tables is the creation of the Ocean Communications City (OCC). Described in publicity as a "technological marvel for the 21st century," the large marine city is the brainchild of Professor Kiyohide Terai, Secretary General of the study group for Ocean Communications City. Indeed, if the concept is realized, it would be the largest and greatest marine engineering and architectural feat since the construction of Venice, Italy. It would be comparable to the United States effort in landing a man on the moon.

The basic plan for the city consists of four levels or decks each measuring 5 by 5 kilometers. Each level would have a height of 20 meters. The

* Walls made of various material to protect an embankment.
** An airtight chamber, open at the bottom and containing air under sufficient pressure to exclude the water.

Table 1. Major existing man-made islands in Japan

Name	Use	Water depth (m)	Wave height (m)	Soil quality	Construction period	Area (1,000 m²)
Ogishima	Industrial land	0–15	3.4	Clay	1971–1975	5,150
Higashi Ogishima	Harbor facility and transportation facility	0–10	—	Silt	1972–1984	4,340
Yokohama Daikoku	Harbor facility greenery	12	5.5–6.0	Silt	1963–1985	3,210
Nagoya Port Island	Soil dump	6–7.5	2.0	Clay, silt	1975–1987	1,140
Nagoya Kinjo	Harbor facility, foreign trade facility, exhibition hall, greenery	0–5	1.0	Soft soil	1963–1985	1,910
Yokkaichi Kasumigaura	Harbor facility, industrial land	4.5–12	4.0	Soft soil	1967–1988	3,870
Gobo Thermal Power Plant	Power plant site	5–18	17.5	Sandstone, sandy soil	1980–1983	350
Osaka South Port	Harbor facility, urban development site, commercial facility, park, greenery	10	3.3	Clay	1958–1984	9,370
Osaka North Port	Harbor facility, industrial land, waste disposal facility	10	3.3	Clay	1972–1988	6,150
Kobe Port Island	Harbor facility, international exchange facility, urban development site	10–13	—	Clay	1966–1981	4,360
Rokko Island	Harbor facility, urban development site	10–14	—	Clay	1971–1985	5,830
Kanda Earth Dump	Dredged sand dump, park	7.5	2.5	Soft soil	1977–1986	1,530
Nagasaki Airport	Airport	10–18	2.0	Clay, basalt	1971–1974	1,630
Mitsui-Miike Island (No. 3)	Vertical ventilation shaft	10	3.3	Soft soil	1969–1970	6
Kansai International Airport	Airport	20	—	Soft soil	1985–	1,200

lowest deck would be 20 meters from the surface of the sea, making the top deck 80 meters above sea level. The area of each deck would be 25 square kilometers for a total surface area of 100 square kilometers.

It is estimated that the city would be able to support a permanent population of 1 million people and be able to accommodate 500,000 visitors. The price tag for this venture has been estimated at $200 billion in 1986 dollars, or 40 trillion yen.

The top deck of the city would support an international airport with two 6-kilometer-long runways (Figure 3). In addition, there would be a sports center with eight golf courses, 400 tennis courts, 2 domed air-conditioned baseball stadiums, swimming pools, and so on. It is also planned to have an international research center for ocean development, as well as other international scientific research centers. The second deck will be given over to a large international business center, including a financial market. The third deck is a living area with 40 percent of the space devoted to roads and parking lots, 20 percent for hotels, restaurants, and shopping areas, and the remaining 40 percent to 5-story buildings for private dwellings. The lower deck would be devoted to utilities and services for the city, such as garbage collecting, water works, energy facilities, and so on. On the lower deck, there also will be a port for 1,000-passenger vessels called Surface-Effect Ships (SES), described as similar to hovercrafts, but much faster (cruising speed between 80 and 100 knots) and providing access to Tokyo, Chiba, Kanagawa, Shiznoka, and other cities in Japan (Figures 4 and 5).

In its conceptual stage, the study group has attempted to envision an extremely advanced and sophisticated central electronics computer facility to coordinate and operate the wide range of technological innovations to be incorporated in the city's design. Discussions have even suggested that perhaps it would house the seventh generation computer.

Professor Terai said that the "legs" supporting the city would consist of, from the top down, a pillar, a ballast tank, and a column. Each leg structure would rest on a specially designed foundation.

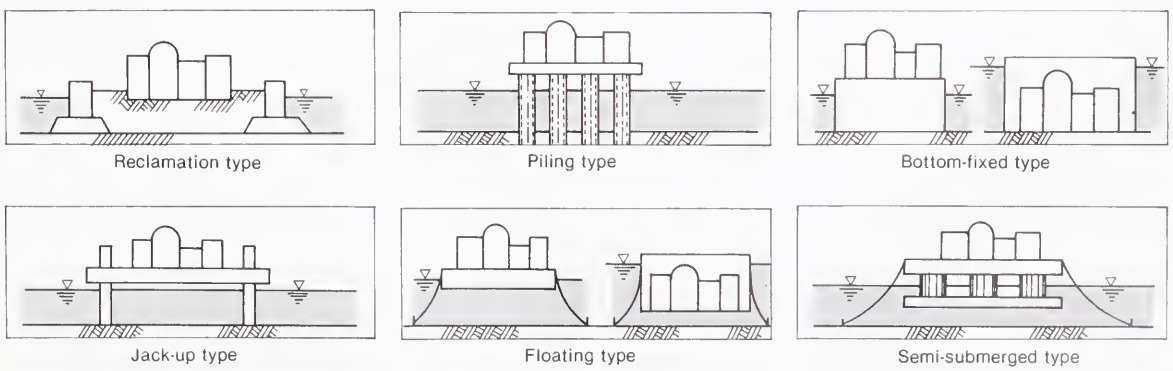


Figure 2. Structural types of man-made islands.

Figure 3. An artist's conception of the top deck of the Ocean Communications City.

Whereas the pillar and tank would have to be strong enough to withstand the dead weight pressure, the column and foundation would be under comparatively little stress because the entire structure would be half-floating. The steel required for the project is roughly 100 million metric tons, which would make it by far the largest steel structure in the world.

Sensors in the legs would monitor changes in pressure arising from local differences between the weight and buoyancy. Information from the sensors would be fed back to a master computer, which would control separate adjustments in individual legs to compensate for any pressure change. If pressure between the legs became uneven, the relevant ballast tanks would be readjusted by increasing or decreasing the water level in the tanks (Figure 6).

Terai said the city's structure could be thought of "as being generally the same as that of a ship in that both are affected by external pressure from waves of varying height and length. Naturally, the larger the wave length and height, the greater the external pressure. The dimensions of the structure and the thickness of the plates normally would have to be increased to compensate, resulting in a large increase in the total weight of the structure. But the computer system for adjustment of both weight and buoyancy is intended to solve the problem without an immense increase in the size of the structure. Recent innovations in corregations of the exterior surface now allow for tremendous increases in strength with a sizeable reduction in weight.

The legs also have a built-in shock absorber called a *SAUCER* (Shock Absorber Used for Column Erection) to make the city safe from earthquakes and tsunamis (Figure 7). Another safety factor is the fact that the city has been designed as a hybrid structure of semi-floating and partially fixed structures. Thus it will be compartmentalized or built in cells.

Looking to the future, Professor Terai leaned back in his plush office in the downtown Tokyo NNT building, Japan's equivalent to AT&T headquarters, and sighed: "In Japan, when transportation is included, it takes a full day [and green fees of $100] to play a round of golf. In our ocean city, offices are located on the second deck, and housing on the third. In 15 minutes, you can be on the golf course or travel (Figure 8) from one point in the city to the next."

The one-day business trip between Tokyo and Washington will become a reality in the 21st century, Professor Terai continued, citing President Reagan's directive this year to NASA to design a

Figure 4. A side view of the Ocean Communications City, consisting of four separate decks.

high-speed plane capable of Mach 25 by the year 1996.

Professor Terai admits that the funding for his city will be difficult. He expects to raise the $220 billion needed for the project both from government and private sectors. At the moment, he has submitted a proposal to the government to build a military training airfield in the waters near the Izu islands off Sagani Bay for the United States as one option among several being considered by the Japanese government, in what has proved a delicate political matter. "The price tag," he said, "would be $200 million and would give us a chance to test and evaluate, on a smaller scale, several of the Ocean Communications City's engineering and design concepts, and also the social ramifications of intensive population settlement in a small area of the ocean.

Training of Ocean Architects

Many of Japan's ocean architects have come from the College of Science and Technology at Nihon University in Tokyo, which has a Department of Oceanic Architecture and Engineering. Professor Wataru Kato, Dean of the college, has written that with the establishment of many 200-mile Exclusive Economic Zones, ocean space itself in Japan became a natural resource. "The need for multi-purpose, efficient utilization of ocean space," Kato notes, "is not limited to Japan alone, but is important as an international proposition. The basic tenet of Oceanic Architecture and Engineering lies in the preservation of comfortable human living conditions and the conservation of the land and water environment in coastal and offshore areas where human life and social activities intermingle closely."

In 1985, Nihon University hosted the First International Symposium on Ocean Space Utilization (the brainchild of Dean Kato) to bring together the world's experts on ocean engineering. The Conference Proceedings (in English) were published as a two-volume set by Pergamon Press in Toyko to bring together an extensive overview of existing knowledge.

The Department of Oceanic Architecture and Engineering at Nihon University has a faculty of 63 members with instruction at both the graduate and undergraduate levels. To our knowledge, it is the only such training facility in the world.

Kenji Hotta, an assistant professor in the department, and an international advocate of ocean space use within environmental parameters, instills the need for new ocean construction theories in his graduate students. "They must conceive their ideas,"

Figure 5. The high-speed 1,000 passenger ferry SES (left) and semisubmersible cargo boat (right).

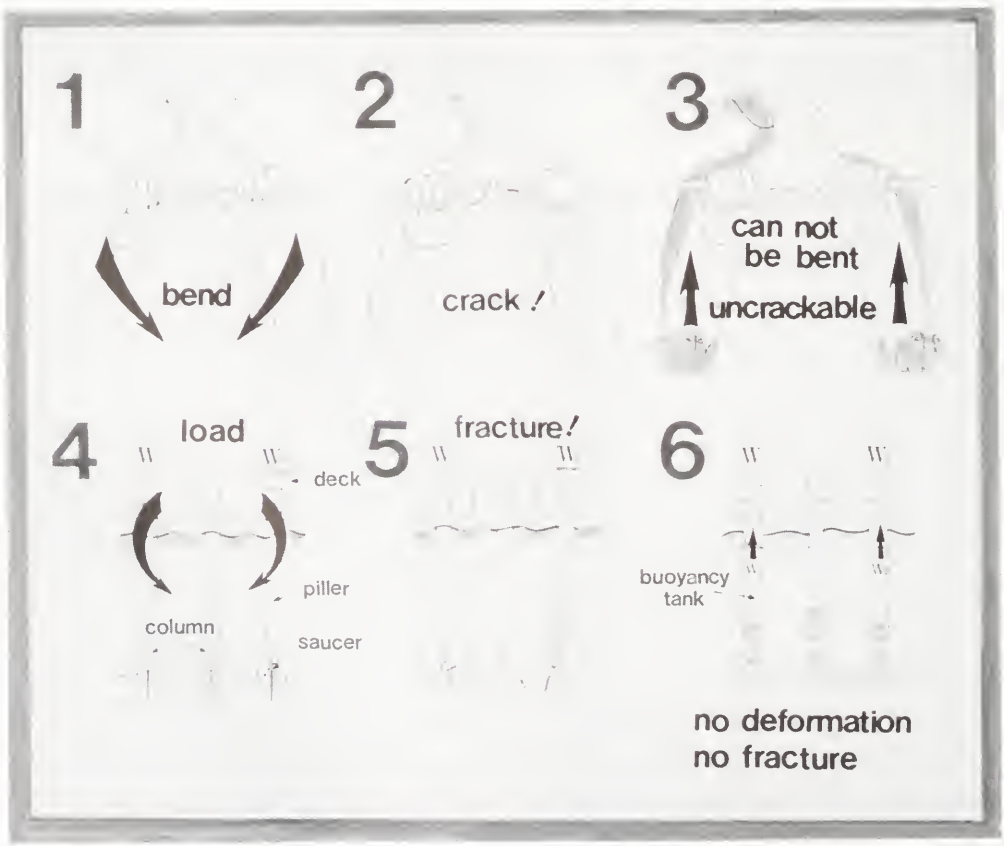


Figure 6. The automatically-adjusting weight control system.

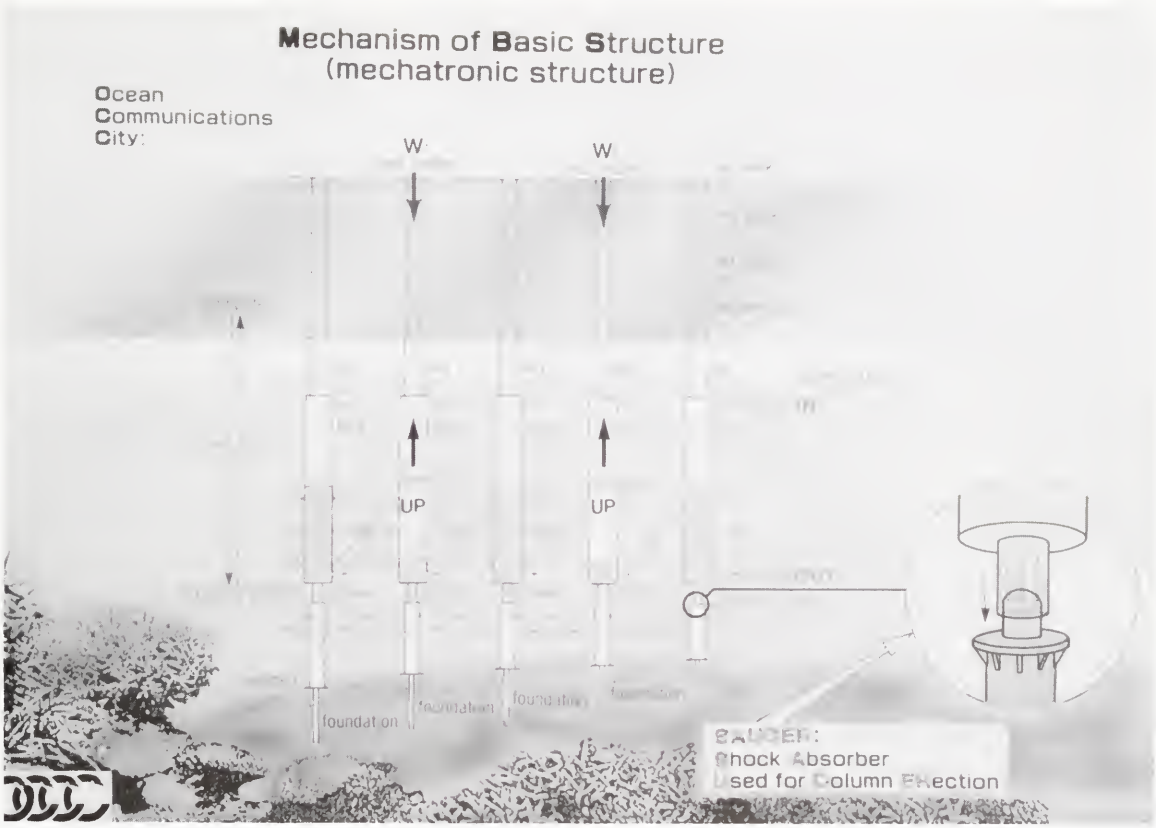


Figure 7. The legs and SAUCER system.

Figure 8. Nonpolluting cars would be provided for city dwellers at a fee. A magnetic card would act as a pass key to any parked vehicle.

he said, "with the knowledge that there is already a high-density in the utilization of offshore space in Japan, what with shipping routes, fish farms, industrial complexes, and the like."

Dr. Hotta, who took his Master's degree at the University of Hawaii and his doctorate in Japan, believes that many other nations in and bordering on the Pacific could use some of the ideas being developed in his department. In fact, he is looking for foreign oceanic architectural challenges for both himself and his students. This fall he will visit countries in Southeast Asia to discuss various ocean space projects.

The Problems Ahead

The problems standing in the way of materializing many of these concepts include coexistence with fishermen, development of the necessary engineering capabilities, centralized management of information on ocean currents, depths, seabed conditions, and winds and waves—not to mention the huge construction funds required.

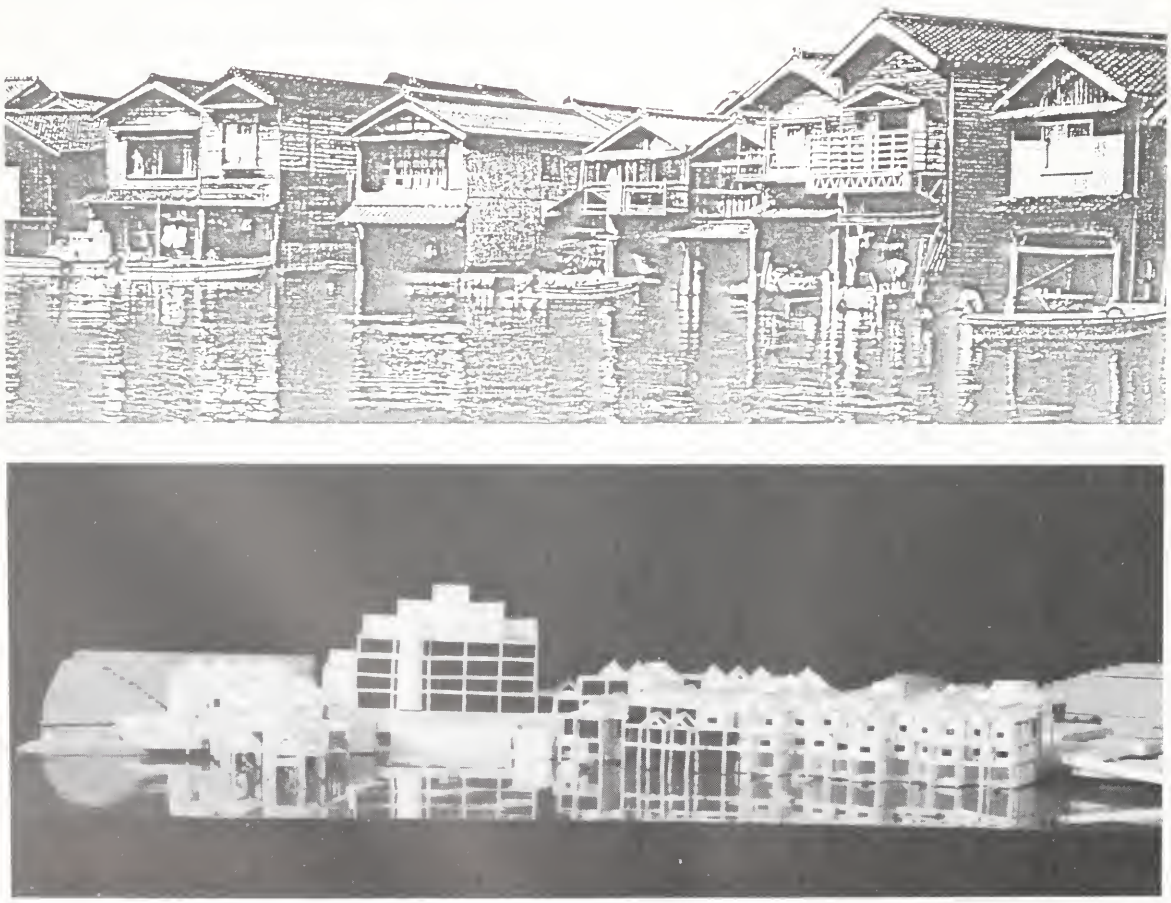
The Japanese, however, do not seem to be deterred by large-scale engineering problems. One they are presently grappling with is the construction of a man-made island in Tokyo Bay that will facilitate the route of the Trans-Tokyo Bay Highway, a combination of tunnel and bridges that will stretch 15 kilometers across the bay (Figure 9). The Chesapeake Bay Bridge Tunnel is an example of a similar but smaller project.

As envisioned, the island will be used for cultural and technical exchanges among people from many countries as well as for providing multi-purpose nearshore space to meet metropolitan Tokyo's increasing demand for ocean recreation and retirement housing for the elderly. The highway, officially begun this year, is a 10-year project. The reclaimation-type island would be located 4 kilometers off Banshu, Kisarazu City, in water depths up to 25 meters.

Applications for U.S.?

Many of the new design and construction alternatives that the Japanese marine architects and engineers are developing have extensive application in many environments; particularly in those that have harsh conditions. The development of new materials and construction concepts will only enhance the longevity of structures on land, let alone for ports, harbors, and marinas. The tremendous advances that will spin off these activities will be of the same nature as teflon or the micro-chip or the many thousands of advanced applications that have come from space exploration and development.

These advances are necessary if coastal



Architectural student's design for modern Japanese fishing village.

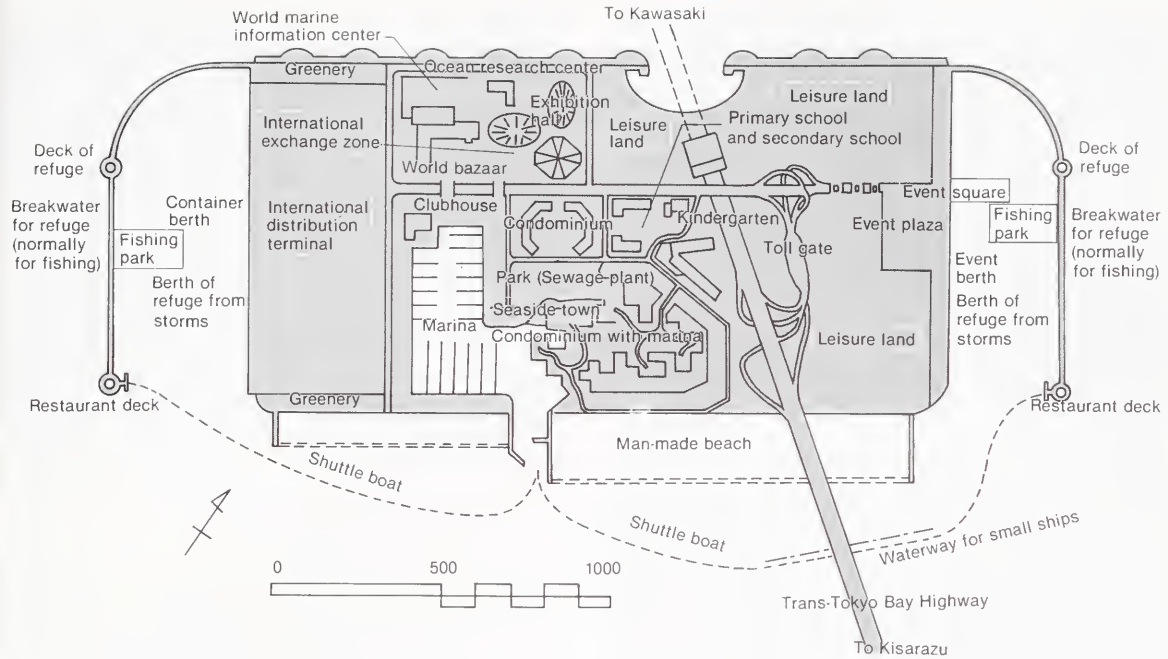
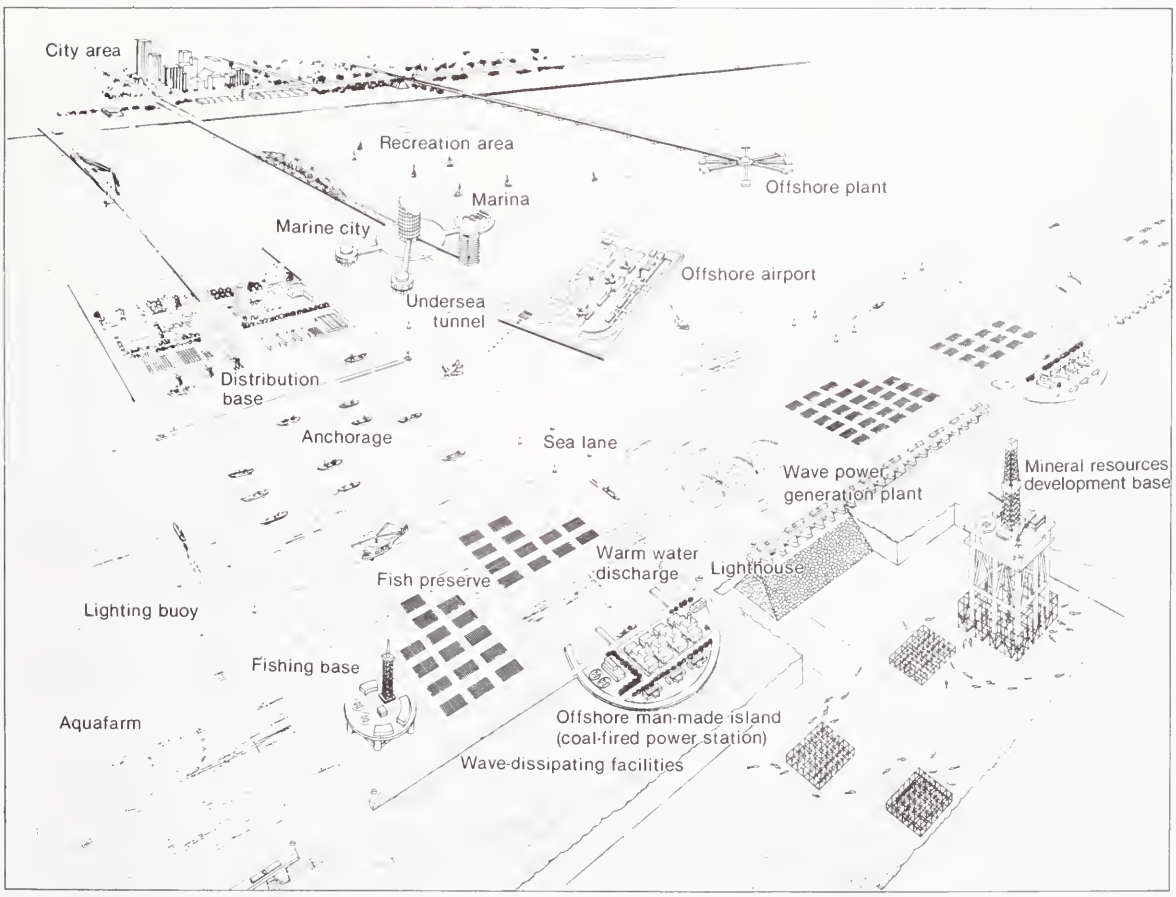
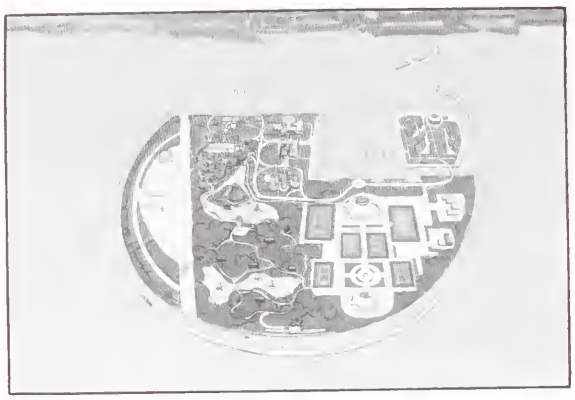


Figure 9. Concept of International Communion Complex planned for Tokyo Bay in the next decade.



Japanese plan for utilization of ocean space in the calm area behind man-made islands.

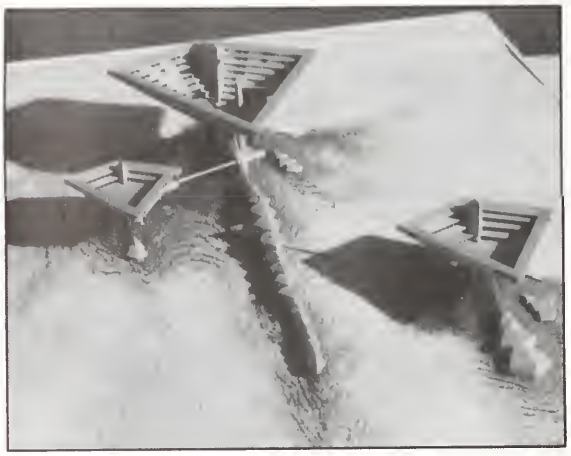
A marine farm on reclaimed land.



A leisure complex.

A coal-fired thermal power plant.

nations are to realize the maximum use of resources (from minerals to ocean space) in their new 200-mile Exclusive Economic Zones. The notion of relocating energy, production, and chemical manufacturing plants offshore of urban areas to reduce the risk of contamination of the coastal environment will become more acceptable in the future. Presently, between 60 and 70 percent of the American population (232 million) lives in the coastal zone (defined differently by individual states, such as according to a roadway or the 100-year coastal flood



Design for base in Antarctica in the year 2001.

plain) and future estimates predict some 200 million people will live in the coastal zone by the year 2000.

Presently, the United States only utilizes ocean space for waste disposal (See *Oceanus*, Vol. 24, No. 1, 1981). The pressures that will develop from the types of urban stresses found in Japan today can be expected in the United States tomorrow. As coastal urban centers reach transportation (both people and goods) limits, the use of coastal waters will become more and more appealing. An example is the recent extension of Interstate-66 in Washington, D.C., which is the most expensive highway ever built in America. It cost more than $1 million per mile because it had to be cut through residential and business areas. Similar expenses are being encountered in the construction of mass rapid transit subway systems all across the United States. Therefore, it is quite possible that offshore development may offer a viable alternative for expanding coastal cities.

Paul R. Ryan is Editor of Oceanus, published by the Woods Hole Oceanographic Institution. He visited Japan in June of this year. Michael A. Champ is Senior Science Advisor at the Environmental Protection Agency in Washington, D.C. He has visited Japan on several occasions.

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Dodge Morgan, the Argos System, and Oceanography

by Paul Ferris Smith

When Dodge Morgan of Cape Elizabeth, Maine, stepped ashore in Bermuda on April 11, 1986, he had been around the world—under sail—non-stop—alone. The voyage had taken 150 days, 1 hour, and 6 minutes—trimming 142 days off the previous record. But, there's more. There is a "story behind the story." While Morgan may have been physically alone, he had several high-tech "companions" aboard to ease his trial. In this way, the voyage illustrates a link between modern satellite technology, ocean sailing, and oceanography.

One of the high-tech "companions" aboard the Morgan boat was an Argos transmitter that allowed—via satellite—the vessel to be tracked at all times. It also allowed Morgan to be advised from shore as to an optimal route. The Argos satellite system has been described by Robert G. Walden, a Senior Research Specialist at the Woods Hole Oceanographic Institution, as "one of the best things that ever happened to oceanography."

The Argos system utilizes two polar-orbiting satellites to collect scientific data from oceanographic buoys or platforms. This remote data transmission is known as radio telemetry. If that were all the Argos System did, it would just be one of a number of useful methods of data transmission. The significant feature of the Argos System, however, is the additional ability to locate the source of the telemetry data anywhere on the world's oceans or world's surface. Further, it does so with remarkable accuracy for a device of this type (300 to 1,000 meters), considering only a small battery-operated transmitter is required.

Sailing Vessels and Oceanography

Particularly in the early days of oceanography, there was a clear link between sailing and oceanography. It can be found, for example, in the career of Columbus O'Donnell Iselin, a leader at the start of modern oceanography, second Director of the Woods Hole Oceanographic Institution, and a scientist who significantly influenced the direction of oceanographic research. Iselin came from a family of proficient and avid sailors. He became involved in oceanography because it offered a challenging professional career that also allowed him to do what he enjoyed so much—sailing—rather than become a banker as had been expected. While an undergraduate mathematics major at Harvard, Iselin, prior to sailing to Labrador one summer, asked Henry B. Bigelow of the Harvard Museum of Comparative Zoology if there was anything he could do for him on the cruise. Five years later, in 1931, when Bigelow was the director of the new Woods Hole laboratory, Iselin became the skipper of the laboratory's first research vessel, the 140-foot ketch *Atlantis*. Iselin was not alone in approaching oceanography from this direction, and love of the sea has led to an understanding of the sea in many other instances. It was not unusual then that Dodge Morgan's voyage should provide a platform for an oceanographic data collection system.

American Promise *arriving off Bermuda on April 11, 1986, completing her non-stop, solo circumnavigation, which began on November 12, 1985. The Argos transmitter is in the small dark box on the aft framework which also supports the radar and other antennas. (Photo courtesy of Manny Morgan)*

The *American Promise*

Dodge Morgan also loves the sea and sailing. By

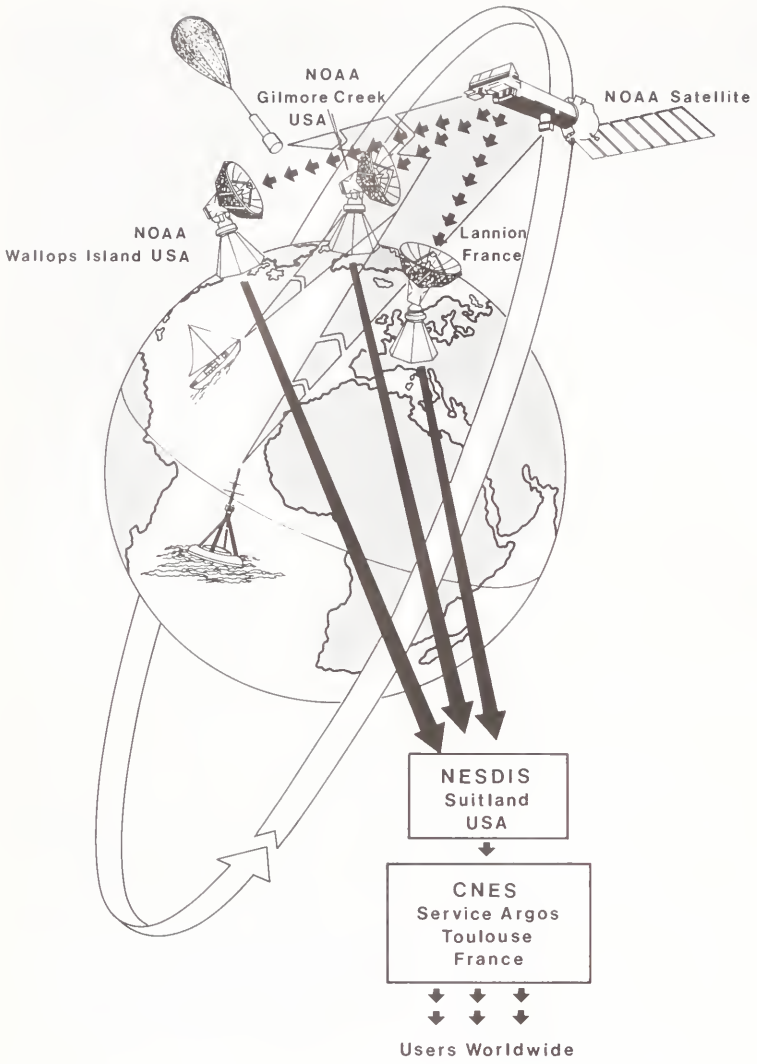


Figure 1. The Argos data collection and platform location system.

selling his company, Controlonics, an electronics firm manufacturing such items as the Whistler Radar Detector, he was in a position financially to undertake this personal challenge, and to do it in a thoroughly state-of-the-art way. He had a boat built for the job—a 60-foot modified sloop designed especially for this globe-circling purpose by "Ted" Hood, and built of fiberglass, Kevlar, aluminum, and stainless steel, in Hood's Little Harbor Boat Yard in Marblehead, Massachusetts. She is called *American Promise*. Redundency and high technology were the order of the day. She had electrically-powered roller-reefing mainsail, staysail, and jib; three automatic pilots; two 11-kilowatt diesel generators; a suite of electronic navigation and communication systems which included two SATNAVs, two single-band transmitters, radar, two ham radio transmitters, plus a computerized monitoring system programmed to alert Morgan whenever conditions, such as wind speed or direction, changed a preset amount. Among the systems aboard *American Promise* was an Argos transmitter.

The Argos System

An Argos transmitter is one component of a satellite system for environmental data acquisition called the Argos Data Collection and Platform Location System. This came about as a result of some early instrumentation developed by the French Space Agency, Centre Nationale d'Etudes Spatiales (CNES), for meteorological balloon tracking, and a 1976 Memorandum of Understanding between the United States and France. This agreement provided for CNES to design and build equipment to go aboard National Oceanic and Atmospheric Administration (NOAA) satellites launched by the National Aeronautics and Space Administration (NASA), and for subsequent joint United States-French system operation.

The Argos system consists of three components: the platform transmitters; the receiving, recording, and transmitting equipment on board two polar-orbiting satellites; and the earth receiving, processing, and communication equipment (Figure 1). The 1976 United States-France Memorandum of

Understanding provided for operation of the system by Service Argos in France with NASA launching the satellites (called the TIROS-N Series, begun in October, 1978); NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) managing the satellites in orbit; and the French Space Agency designing and supplying the on board satellite equipment. These same polar orbiting satellites monitor daily atmospheric temperatures worldwide, have five imaging channels, and receivers and transponders for the Emergency Search and Rescue Beacons well known to aviators and mariners. This satellite series is planned to be maintained through the 1990s with a doubling of the Argos capacity scheduled for 1995.

In operation, the individual platform transmitters send, for about 1 second, a very stable 401.650 megahertz signal at regular 60-second or 100-second intervals. This signal contains, via FM modulation, an identifying code word and such other data as desired that can be fitted into the 256 data bits allowed per transmission. The satellite equipment receives and records this transmission whenever the transmitter is in the line-of-sight "visibility" area of either satellite.

The two polar-orbiting NOAA satellites are at approximately an 850-kilometer altitude and circle the earth every 101 minutes. Their orbits are essentially at right angles to one another. At the 850-kilometer altitude, the "visibility circle" or "footprint" is 5,000 kilometers in diameter. The satellite can receive radio signals from anywhere within this "footprint." Because the earth rotates 25 degrees to the west under the satellites during each orbit, the footprint shifts with each satellite pass. This adds up to any one Argos transmitter being able to transmit to the satellites 28 times per day, if located near the poles, and about 6 times per day, if at the equator, for a practical average of about 10 transmissions each day from most places on earth.

The secret of the system lies in the high frequency-stability of the 401.650 megahertz transmissions. For, just as police radar can determine the speed of a motorist by the Doppler frequency shift of the radar echo off the moving vehicle (a physical phenomenon named for the Austrian physicist, Christian Doppler, who first described it in 1842), the satellite receiver can measure the alteration of the 401.650 megahertz frequency due to the relative velocity of the fast-moving satellite and the essentially stationary, or very slowly moving, platform which carries the Argos transmitter. When this information, recorded aboard the satellite and relayed to Argos ground stations, is computer-processed (in Toulouse), it yields a circular line of possible positions of the transmitter for each reception. This circle, centered on the satellite's orbit, intersects the Earth's surface in two places. Based on prior information, one is discarded, and the other is plotted as the location of the transmitter. While the orbit of the satellite is known approximately, additional data is required if the computed positions are to be as accurate as possible. Signals from 10 accurately-surveyed fixed transmitters installed around the earth by Service Argos, called orbitography beacons, provide the information for this purpose.

Dodge Morgan surrounded by his wife and two children being congratulated and interviewed as he returns to Portland, Maine, on May 1,1986—shortly after completing his circumnavigation in Bermuda. (Photo courtesy of Manny Morgan)

From Toulouse, where all the data are archived, Argos users can receive the information about their transmitters through data transmission networks such as Telenet, Telex, and the international weather service Global Telecommunications System, or by receiving printouts or computer tapes containing their data. In June of 1986, there were 886 Argos transmitters worldwide. From two to six hours after their signals are received by the satellite these data are available to the user. In addition to oceanographers, users include hydrologists monitoring river basins, such as the Niger, the Amazon, the Loire, and the Seiné; vulcanologists and seismologists monitoring Mt. Etna; biologists tracking whales, seals, sharks, turtles, and birds; arctic meterologists using ice buoys; and, ships and sailing vessels which can collect environmental data and be tracked while they are engaged in ocean transport or globe-circling races. In fact, this maritime-type application is expected to increase as nations monitor fishing fleet activity, and shipping companies increasingly manage ship routing.

One reason that Argos is attractive to oceanographers is that the complex components of the Argos system are few, and they are aboard the satellite and in the ground stations, rather than in the more hostile environment of the sending platform. One of these Argos transmitters contained in its own weatherproof box with a battery aboard *American Promise* made it possible for Morgan's friends, relatives, wife, and weather advisor to track the voyage at all times.

Argos Aboard *American Promise*

As a sailor who often left loved ones ashore, Iselin would have appreciated Morgan's use of Argos aboard *American Promise*. For, just as ocean scientists can come into their laboratories each day and, using their electronic mail system, interrogate

the satellite data processing center to learn immediately where their buoys are in the Yellow Sea or the Indian Ocean, Morgan's wife, Manny, could check daily on his progress in the same way from their home in Cape Elizabeth, Maine. This process involved calling Service Argos, the French operated Argos Processing Center in Toulouse, through the electronic mail service Telenet using a suitable terminal and modem. In addition, Argos has an automatic emergency alert function. In an emergency situation, a switch can be activated. The ensuing transmitted message alerts the processing center, and notification (and location) is forwarded promptly to search and rescue authorities.

The ability of Argos to track Morgan seemed to make that small transmitter a most important piece of equipment, particularly to those ashore. One of these was Robert B. Rice of Weather Services Corporation, Bedford, Massachusetts—his meterological advisor. By combining the Argos track data (available even when radio-telephone communication was interrupted or sparse) with satellite image data and conventional weather maps, Rice was able to advise Morgan, via ship-to-shore radio-telephone, about the best route, the weather to be expected, and, in one case, the possibility of icebergs on the track. Morgan did have his share of weather. Exactly, according to Rice, what one would expect for that time of year and ocean areas. The result: *American Promise* was tested; and so was Morgan. Both passed.

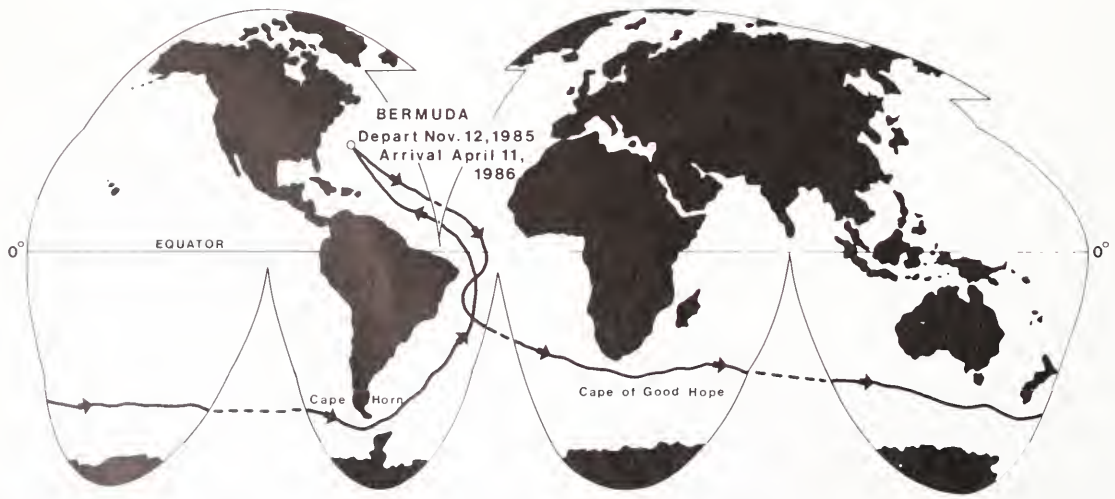
In the southern Pacific, they were "knocked down to 70 degrees" and the spar touched the water often. But the Hood-designed cutter had a positive righting moment and always came back up. Dodge reported that his main problem was picking up down below after these knockdowns. He did, however, suffer a sprained back once. Unexpectedly, one place he did not suffer was rounding the Horn, where he sighted the rocky islands of Diego Ramirez at 0530 local time on February 28, 1986. The visibility was perfect for an hour and he could even see the lights of Chile 45 miles distant. Southwest winds of 15 knots were punctuated by passing squalls and gusts.

The *American Promise* did take a beating in the Southern Ocean, crashing down sideways off 40-foot waves. Apparently this was when her main engine V-drive was disabled, so that this power plant could not be used to charge the batteries, make fresh water, or even to put into Bermuda after sailing across the line off St. David's Head at 1217 local time on April 11.

Previous record holders shared the adventure, but not the technology of Morgan. The existing record had been set in 1971 by Chay Blyth aboard the 59½-foot ketch, *British Steel*. Morgan also beat the fastest solo, 4-leg, 3-stop, single-handed, record of 159 days (which does not include layovers) set by Philippe Jeantot aboard the 56-foot aluminum cutter, *Credit Agricole* during the 1982–83 BOC Challenge Race. Morgan accomplished this astonishing record by sailing continuously. This is where high-tech aids, and a heavy sea-kindly hull design which spared the skipper, paid off. He kept the *Promise* moving. As a result he had only one significantly poor passage day (60 miles) in the doldrums (the intertropical convergence zone near the equator), and averaged better than 170 miles per day overall. His best run was 236 miles, and that was on his birthday.

Ocean Applications

Understanding ocean circulation is central to understanding many oceanographic processes, such as fish larvae dispersion, nutrient cycling, air-sea interaction, weather and climate, as well as the basic physics of the oceans. Buoys moving with the



The non-stop solo voyage of the yacht American Promise, *November, 1985, to April, 1986.*

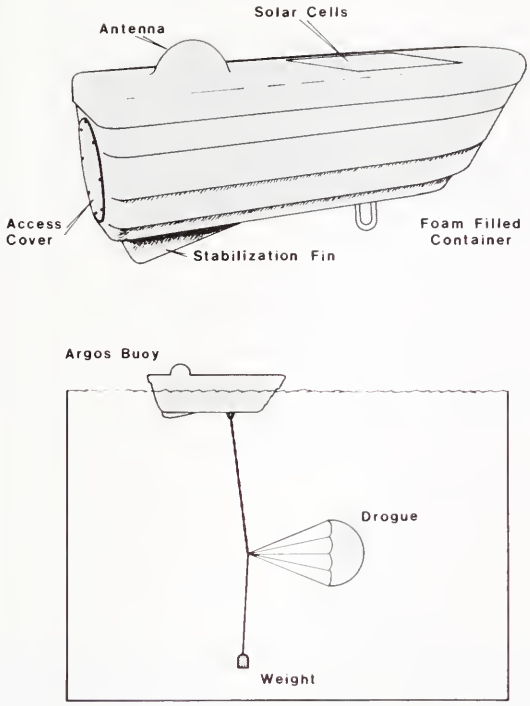


Figure 2. One type of Argos-tracked drifting buoy with parachute drogue—weighted to stay at a selected depth—where the currents under study pull it and the buoy along, indicating the path of the current.

currents, each equipped with one of the battery operated Argos transmitters, is an effective way to track and thus understand these currents. Many ongoing research projects are doing just this. In these research applications, data are sent as a frequency modulation (FM) of the 401.650 megahertz carrier signal. These data can be, for example, air and sea water temperatures, barometric pressure, wave measurements, wind speed and direction, and humidity. One of the most interesting of these buoys is the RELAYS (Real-time Link and Acquisition Yare System) Buoy developed by Walden and his Woods Hole Oceanographic Institution colleagues. It has, suspended 1,100 meters beneath it, a hydrophone for receiving acoustic transmissions from submerged neutrally-buoyant drifting buoys tracking deep ocean currents.

Surface-drifting buoys track currents by having a drag element or drogue (such as a parachute) suspended beneath them at the depth of interest—near the surface, 100 meters, 300 meters, or more (Figure 2). The buoy moves, not with the wind or waves, but with the currents acting on the drogue. This technique was used recently by James R. Luyten, Associate Scientist at the Woods Hole Oceanographic Institution, to describe the Agulhas Current Retroflection off the southern tip of Africa. In this case, the drogue was set 15 meters deep to move the buoy with the near-surface current.

The Future of Argos

The World Ocean Circulation Experiment (WOCE), a multi-year program beginning in 1987, described as "probably the most complex program the world oceanographic community has every attempted," plans on extensive use of Argos to track and receive data from a half dozen different types of buoys. In this instance, the experiment depends heavily on Argos and a variety of other satellite-based systems. Data, such as wind velocity and sea-surface temperature measurements, obtainable by conventional means (principally research vessels and moored buoys) would not provide the global scale of coverage sought. Therefore, some 4,000 of one type of Argos drift buoys are planned for WOCE, and another buoy type under design will track deep currents, periodically surfacing to communicate its position and telemeter data through Argos.

In another development, since more than 50 percent of the Argos transmitters currently in use are operated by organizations in North America, a U.S. processing center for Argos data is scheduled to be opened in early 1987 in Suitland, Maryland, under the administration of Service Argos.

Paul Ferris Smith is Staff Oceanographer with Ferranti O.R.E., Inc., Falmouth, Massachusetts, manufacturers of the Argos transmitters and Argos-equipped buoys.

URI Symposium Report: The Future of the World's Oceans

—Waste management seemed to be the key phrase of the day.

by James H. W. Hain

At the University of Rhode Island's "Future of the World's Oceans" Symposium on July 3, 1986, a seven-member panel, moderated by Edwin Newman, attempted to look ahead to the Year 2020. (All photos courtesy Univ. of R.I.)

On July 3, 1986, a one-day symposium on "The Future of the World's Oceans" was convened at the University of Rhode Island, Kingston, Rhode Island. The event was a part of the commemoration of the 350th anniversary of the founding of Rhode Island, "The Ocean State," and simultaneously, the 25th anniversary of the founding of the university's Graduate School of Oceanography.

The seven-member panel was moderated by former NBC newsman Edwin Newman. The panel members were:

- Willard Bascom (profiled in *Oceanus*, Vol. 27, No. 2, pp. 63–67). A Research Associate at the Scripps Institution of Oceanography; an ocean scientist, engineer, explorer, miner, and inventor.
- John A. Gulland. Senior Research Fellow, Imperial College, London; and former Chief, Marine Resources Service, Fishery Resources and Environment Division, United Nations Food and Agriculture Organization (FAO), Rome. Widely recognized in international fisheries science and management.

- John A. Knauss. Dean of the Graduate School of Oceanography, University of Rhode Island; and former Chairman, National Advisory Committee on Oceans and Atmosphere (NACOA).
- Kenji Okamura. Technical Advisor, Mitsubishi Heavy Industries; and former Executive Director of the Japan Marine Science and Technology Center.
- Cecil J. Olmstead. Attorney, Steptoe & Johnson, Washington, D.C.; former vice-president, Texaco; and delegate, United Nations Conference on Law of the Sea.
- Dixy Lee Ray. Retired; consultant to the U.S. Department of Energy, and others; former Governor, state of Washington; and former Chairman, U.S. Atomic Energy Commission.
- Stansfield Turner. Retired; former Director of Central Intelligence under President Jimmy Carter; Admiral, U.S. Navy; former Commander-in-Chief of NATO's Southern Flank, Naples, Italy; and 36th President of the Naval War College, Newport, Rhode Island.

Dixy Lee Ray, "The sub-seabed disposal of high-level radioactive wastes is a course dictated by common sense and scientific knowledge."

Recognizing at the outset that the future of man and the future of the world's oceans are closely linked, and considering the balance between both the use and the preservation of the oceans, the panel attempted, with due caution, to peer into the future—looking forward to the year 2020. As they did so, the inextricable interweaving of politics, policy, economics, and science was in evidence throughout.

Waste Disposal

The oceans will play a greater role as a total waste disposal system. (See also "The Oceans as Waste Space?" *Oceanus*, Vol. 24, No. 1.) To avoid polluting the valuable groundwater beneath the land on which we live, we will increasingly look to the oceans. Knauss suggested that "the ocean is a great place for waste disposal," and that "a total program of 'Waste Management' is coming of age!"

With regard to disposal of high-level radioactive wastes, the ocean was seen as the preferred option—specifically the burial in the sub-seabed of specially-designed containers in deep, geologically stable, and remote areas; for example, in the mid-Pacific (see *Oceanus*, Vol. 20, No. 1). In an ensuing exchange with the audience, Ray stated that the problem of high-level radioactive waste disposal was not a scientific problem, but (rather) primarily a public perception problem, and that sub-seabed disposal represented a course dictated by "common sense and scientific knowledge."

Continuing on the topic, Knauss cautioned that, "The environmental movement, in order to make its case, has overstated its case—particularly with regard to radioactive waste. The environmental movement will therefore have to take on an increased responsibility for presenting the facts accurately" (See also page 18).

Pollution

While pollution in coastal areas and enclosed bodies of water is, and will continue to be, a problem, pollution of the open ocean may be oversold. Here, man's effects, while detectable, will likely not be significant.

Non-point-source pollution (runoff from rivers and agricultural lands, for example) are less publicized, quite important, and difficult to control and rectify. Knauss said the daily pollutant load dumped by the Hudson River into Long Island Sound is greater and more damaging than the more highly-publicized sludge barges sent out from New York City.

While Ray and others pointed out that water quality in many areas of the United States was better today than 20 years ago, Gulland reported that the water quality in other countries continues to deteriorate, and that the turn-around point in these areas is probably still years away.

Continuing on the topic of water quality, Olmstead pointed out that in some cases (the Connecticut River, for example) the water quality had been allowed to deteriorate a long way before clean up decisions were made. He called for improvements over what has been, at times, a haphazard maintenance of the desired balance. Knauss added that while it is possible to clean up a river within man's lifetime, that, should the oceans be allowed to deteriorate to similar levels, a cleanup would be considerably more formidable, and not achievable within a single generation.

National Defense

Turner foresaw a general movement to the sea. The U.S. nuclear deterrent forces will become increasingly dependent on guided-missile submarines, because of their greater invulnerability. We will move away from the more vulnerable land-based systems. There will be an overall reduction in nuclear arms. Despite an existing treaty banning the placement of military weapons on the seabed, this topic may well come up for re-examination. The contest between innovations in submarine-detection and submarine-concealment will continue with vigor.

Food From the Sea

"Food from the sea," one of the catch phrases of the 60s and 70s has been toned down. There will likely be only slight additional increases in oceanic productivity. Realized productivity gains will likely come mostly from an improved utilization of the same species as are presently caught (examples mentioned products like "surimi,"* and "fish sausages").

Knauss suggested that genetic engineering would yield fast-growing, and thus more productive, strains of existing species. This would contribute to what he sees as "fantastic improvements in the field of aquaculture." But, the panel indicated, due to legal and social issues restricting the use of shorelines in the U.S. and other developed countries, the major advances in mariculture will come elsewhere. Ecuador and Sri Lanka were among those named.

Deep-Sea Mining

Another of the focus-points of the 60s and 70s seems to have fallen by the wayside. Bascom, himself an explorer and miner, provided an update. Ocean mining now appears to be a "poor bet." The political, economic, logistic, and technological constraints on deep-sea mining mean that the same mineral (or acceptable substitutes) can be mined cheaper and easier on land. This applies to cobalt, manganese, molybdenum, and others.

Law of the Sea

With regard to the United Nations Third Convention on the Law of the Sea, concluded on 10 December 1982 and now awaiting ratification, the United States is at present in an awkward and ambiguous position. Conflicts in ocean use are likely to increase in the future. In the absence of participation in the working treaty, Olmstead pointed out, the U.S. will not have access to the international mechanism for resolving those conflicts. Knauss was hesitant about approaching the year 2020 without U.S. participation in an international law-of-the-sea treaty. "We should go back to the table," he said.

Offshore Oil and Gas

Prospects of oil and gas exploration in the Atlantic are slim, under present conditions, according to

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* Surimi is a fabricated elastic seafood product used for a variety of purposes, including shellfish simulation. It is a Japanese term for mechanically-deboned fish flesh (usually pollock or hake) that has been washed with water. It has a high protein level. For additional information, see *Oceanus*, Vol. 27, No. 1, p. 35.

Stansfield Turner foresaw a general movement to the sea for the United States' defense and nuclear deterrent program.

John A. Knauss, "Genetic engineering will lead to fantastic improvements in the field of aquaculture."

Olmstead. Exploration that does occur will take place elsewhere, in existing fields, on the perimeter of existing fields, or in what are regarded as low-risk areas. Exploration in frontier areas will await the next energy crisis—which, Olmstead predicted, will occur in the early 1990s. Shortages of oil and gas will again occur, followed by a boom in exploration. Then, finds will likely be in the deeper strata. There was disagreement among the panelists as to whether oil and gas would become scarce by the year 2020, or whether it would still exist in sufficient quantities. This went unresolved.

A related problem concerned the oil rigs themselves. During the next 30 years, several thousand (the number 4,000 was mentioned) oil rigs are headed for obsolescence. These structures will have to be dealt with. How? Where? Offshore reefs? This question, too, awaits a future solution.

A second ancillary topic was brought forward. There was concern that pollution from tankers may be on the increase. Olmstead attributed this to a shift in tanker ownership—to an increasing number of "single-tanker corporations." In these instances, liability does not extend beyond a particular carrier. When this occurs, it is believed, there is less control, and less incentive for accepted procedures of tank flushing and dumping. Tar is increasingly in evidence, for example, on the beaches of the Caribbean. Concern was expressed that pollution limits in this region are being approached.

Unpredictability and Surprises

At several points during the course of the day, Knauss injected cautionary notes about the panel's forecasts. "We're not very good at predicting the future," he said. "Looking back, we were right about some things, and wrong about others. For example, we never would have guessed two of the major factors influencing today's oceanography. That is, the role played by satellites (see, for example, p. 63), or the computing capabilities now available to marine scientists. I'll be astonished if we don't have a number of similar surprises in the next 30 years."

Balance in Jeopardy

In all, by day's end, it appeared that several of the visions of the 60s and 70s had been dismissed or downgraded. Among them were Ocean Thermal Energy Conversion (OTEC), wave power, sail power, floating cities (see article on Oceanic Architecture, p. 52), floating nuclear power plants, food from the sea, and deep-sea mining. In a summary, Dennis W. Nixon, Professor of Marine Affairs at the University of Rhode Island, said the panel had suggested a gradual evolution, rather than a major revolution, in the interaction of man and the oceans. The indications were, however, that the balance between the use and the preservation of the ocean would become increasingly difficult to achieve and to maintain.

Cecil J. Olmstead, "The next energy crisis will occur in the early 1990s."

James H. W. Hain is Assistant Editor at Oceanus, published by the Woods Hole Oceanographic Institution.

Letter Writers

The editor welcomes letters that comment on articles in this issue or that discuss other matters of importance to the marine community.

Early responses to articles have the best chance of being published. Please be concise and have your letter double-spaced for easier reading and editing.

Staying Alive— Sea Grant and the Budget Battle

by Lauriston R. King

For six years, the Reagan budget cutters have sought to end federal support for the National Sea Grant College Program. Each time, Congress has put the money back in what has become a numbingly predictable standoff between the President and Congress. But six years of political turmoil have had a profound impact on Sea Grant's structure, political behavior, and research capabilities.

Photo above: a major part of Sea Grant research and advisory services are directed toward enhancing the use and management of the nation's fisheries resources. (All photos courtesy of Norman Martin)

The Sea Grant Program

Congress set up Sea Grant in 1966 to bolster the nation's capabilities to understand, use, and develop marine resources. After 20 years of modest federal support—never more than $42 million in any one year—the Secretary of Commerce has designated 21 Sea Grant Colleges. Eight others have major institutional programs, and an estimated 230 additional schools and colleges have taken part in the program. In dollar terms, federal support for Sea Grant is a tiny portion of the billion-dollar federal ocean budget.

The small Sea Grant community received a harsh jolt in early 1981 when the new administration targeted the program for the budgetary scrap heap. There was no reason to expect that Ronald Reagan's victory would drastically affect Sea Grant's fortunes. Indeed, in a report prepared to guide the new government, the conservatively-inclined Heritage Foundation recommended a 10 percent increase for each of the next five years.

The decision to cut Sea Grant funds had little to do with any drastic shortcomings in the program. From the time of the first Reagan budget, issues of environmental protection, conservation, and resource management were totally dominated by the budget and tax reduction goals of the administration. Ocean matters, a tiny part of this family of environmental concerns, were overwhelmed by this strategy of redirecting policy through cuts in

domestic spending and increases for defense.

Sea Grant Response

Sea Grant was quick to draw on its political assets. First among these was unwavering bipartisan support in Congress. Congress created Sea Grant, so paternal pride was clearly at stake. Equally important, of course, was the political reality of a program that delivered information and services in coastal towns and counties around the country. Constituents were quick to let their representatives know about their support for the program.

Sea Grant directors, advisory agents, and information specialists reinforced Congress' positive views. They presented themselves as a cohesive organization, free of internal dissension, with a clear sense of mission, strong constituent support, and the ability to provide large amounts of information to support their case. Indeed, one of the most compelling bits of support came early in the fight when Sea Grant determined that the $270 million of support during its 14-year history had stimulated gross revenues and savings amounting to some $227 million *annually* for marine industry, commerce, and government.

Finally, most Sea Grant directors, unlike many academics, were no strangers to politics. To be sure, this political experience involved fairly routine congressional contacts at budget time, and the more intricate brand of politics played within their states and universities. But this experience was important, since the survival fight could not have succeeded without an appreciation for sound political intelligence, accurate information, and an understanding of the political process.

Survival Efforts Aid Program

No program that scraps for survival six years in a row comes out unscathed, and Sea Grant is no exception. Curiously, however, the effects of the fight have not been all bad. In battling for its existence, the program has evolved into a stronger, tighter, and better organized effort than it was in 1980.

This change is evident in three areas—planning, integration, and political organization. To demonstrate that it was attuned to national as well as state and regional issues, Sea Grant sharpened its planning efforts to identify research priorities in a variety of fields, including biotechnology, estuaries, and aquaculture.

These sharpened planning efforts also have hastened the integration of the Sea Grant network. This process has involved joint planning between programs, the sharing of specialists, the creation of regional organizations, and development of a national communications program. The centerpiece for this effort is *Sea Grant Abstracts*, a quarterly listing of publications from throughout the network released in mid-1986.

The most ironic aspect of these six years of political turmoil is that instead of killing the program, the Administration triggered a response that spawned a far more self-conscious and effective political organization than existed in early 1981. Even more important, the Sea Grant political experience has been the catalyst for raising the political awareness of other parts of the marine science community and getting these organized through the recently established Marine Division of the National Association of State Universities and Land Grant Colleges. In short, the actions of the Reagan administration created a political organization among marine scientists where none had existed. They had succeeded where others had failed: they had uncorked the political genie.

Impact of the Budget Battle

If some good has come from the budget battle, it may well be overwhelmed by the long-term consequences of level-funding. Table 1 shows the pattern of federal funds between fiscal years 1980 and 1987. The pattern is clear: there has been virtually no growth in the program, and the first signs of erosion already have been identified.

Between 1980 and 1985, the share of federal funds invested in research has declined from 49 percent to 44 percent (Table 2). The inexorable increases in people costs—salary, insurance, travel, pensions—can only continue to erode the research base. The cost will be high. For instance, without some realistic expectation of long-term stable support, researchers shy away from Sea Grant and projects are too often under-funded. There is a temptation to support familiar kinds of research that promise short-term results rather than more broadly defined, innovative efforts. Sea Grant managers are faced with what is becoming a chronic dilemma, namely, how to continue to fund productive researchers over the long haul, yet still bring promising new scientists into their programs.

Donald Squires, former Director of the New York Sea Grant Institute, surveyed his colleagues to determine the effects of declining support. They reported that the greatest impact was on research. Fewer projects have been supported and promising avenues have been deferred. For example, the average number of research projects in a Sea Grant program dropped from 31 in 1980 to 25 in 1984. During this same period, average project costs climbed from $40,000 to $46,000. Programs lost an average of six research faculty members from their efforts.

Education also has been hit hard. Some 40 percent fewer graduate students were being trained in 1985 than in 1980. Programs in elementary and high school education were sharply reduced or eliminated.

The decline of research efforts is especially troublesome. Training and transfer activities are well established through the education, advisory, and communications programs. But unless the store of knowledge is renewed through research, these mechanisms are destined to atrophy.

Table 1. Federal Sea Grant funding, fiscal years 1980–1987 (in millions of dollars).[a]

Fiscal Year	Total Federal Obligations
1980	38.7
1981	41.8
1982	35.0
1983	35.0
1984	36.5
1985	39.0
1986	39.0
1987	39.0[b]

[a] Source: Office of Sea Grant, National Oceanic and Atmospheric Administration, Department of Commerce
[b] Estimated

Table 2. Percentage of federal funds for Sea Grant research, advisory, and education activities, fiscal years, 1976–1985

Fiscal Year	Research	Advisory	Education
1976	52.3	23.8	8.2
1977	52.1	27.4	11.7
1978	43.8	23.8	11.4
1979	52.2	29.1	11.0
1980	49.6	26.2	9.4
1981	45.5	28.6	8.7
1982	45.2	28.8	7.2
1983	45.9	28.8	8.2
1984	44.6	29.5	6.1
1985	44.3	30.1	5.5

Source: National Sea Grant Office, National Oceanic and Atmospheric Administration, July 1986.

Funding Crucial

Survival is no longer the issue for Sea Grant. Barring a major economic crisis, Congress is not likely to preside over its demise. The real question is whether there will be enough federal support for Sea Grant to do its job. Federal dollars are critical because they not only account for most of the support, but also provide the leverage for attracting support from state and local governments and industry.

The current pattern of declining support has already resulted in an ominous reduction in the share going to research. Level funding also has stymied the development of the network's full capability by inhibiting the growth of emerging programs like Connecticut, New Jersey, and Ohio, and prohibiting any growth in established Sea Grant Colleges.

At a more speculative level these conditions—no growth, few opportunities to expand into promising new research areas, and unfilled staff positions—threaten to gnaw away at the driving force for Sea Grant—the enthusiasm of its people. It is quite conceivable that the imaginative, energetic, and talented people who have been drawn to the Sea Grant mission will weary of the constant political turmoil. Indeed, they may despair at not having the resources to build the kind of sustained program required to meet the nation's many needs and

Recreational demands on coastal and marine resources have grown dramatically as Americans have continued to settle in the coastal zone. In recent years, Sea Grant researchers have sought to document the economic contributions and social aspects of marine recreation.

opportunities in the oceans. This is simply not a very attractive opportunity for the long term.

There is no clear evidence that this is the case right now. But when folks begin to leave the advisory service for other jobs, and university administrators drag their feet in filling top Sea Grant positions, then it is time to examine these responses closely for they may well be symptoms of a broader pattern of eroding capabilities.

In short, Sea Grant has survived. In many respects, the program has been strengthened as a result of its ordeal. It has learned from a political education of the first order. Many of its leaders have become articulate spokesmen for the ideals and achievements of the program. Research priorities have been identified. Collaboration between and among programs and government agencies has augmented the capabilities of the network.

But without an attitude on the part of public officials that views federal funds for Sea Grant as an investment, the prospects of this flexible and effective institution realizing its full potential in the foreseeable future is not especially promising. Good work will continue to be done, but opportunities will be missed. Personal commitment to the program will decline amid chronic uncertainty, and the character of the overall program will change as previously protected parts of the program, such as advisory and communications, begin to suffer cutbacks to sustain a minimal research program.

Congress created a flexible and geographically diverse organization in Sea Grant, one capable of inspiring great loyalty, commitment, and enthusiasm. In the 20 years of its existence, the program has already occupied a special niche among the nation's marine programs and demonstrated its ability to contribute to ocean development. It would be a regrettable concession on the part of the American people to allow it to wither away.

Lauriston R. King is Deputy Director of the Texas A&M Sea Grant College Program and Adjunct Professor of Political Science at Texas A&M University, College Station, Texas.

Training teachers about the marine environment enables them to nurture an enhanced awareness among their students of their ties to the oceans and their resources. Education programs have been among the hardest hit by declining support for Sea Grant.

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The views presented in this article are those of the author and not necessarily those of the National Sea Grant College Program.

Among the areas where Sea Grant researchers have made important advances are aquaculture, biotechnology, environmental chemistry, and seafood technology.

EPA Puts the Ice on Ocean Burns

by Sally Ann Lentz, and Clifton E. Curtis

The Vulcanus II ocean incineration ship, owned by Chemical Waste Management, Inc., in the North Sea in November of 1983. Whether smoke represents the burning of waste or the oil-fireup of incinerators is disputed. (Photo courtesy of McAllister/Greenpeace, 1983)

Plans to conduct research on burning toxic wastes at sea were dealt a blow this spring when the U.S. Environmental Protection Agency (EPA) denied Chemical Waste Management, Inc., the worldwide leader in hazardous-waste disposal, a research permit to incinerate 700,000 gallons of polychlorinated biphenyl (PCB)-laden liquid waste about 120 nautical miles off the Northeast coast. Assistant Administrator for the Office of Water, Lawrence J. Jensen, based his denial of the permit on a set of complex legal, scientific, and technical concerns associated with the proposed research (see *Oceanus*, Vol. 27, No. 1, pp. 70–74). As a result, the EPA will issue no permits for burning at sea until special ocean incineration regulations have been promulgated. The decision places the Agency (EPA) in something of a Catch-22 position. On the one hand, EPA has expressed the view that it will issue no permits until regulations have been written. However, without the research data from a test burn, it will be difficult for the Agency to develop appropriate regulations. This recent development leaves the future of ocean incineration uncertain for the United States, and could influence policies abroad.

EPA's Proposed Test Burn

The proposal by Chemical Waste Management, Inc., to conduct a research burn is linked, in part, to an April 1985 report of EPA's Science Advisory Board (SAB). The SAB indicated that research to date on ocean incineration technology did not conclusively demonstrate the ability of the incinerators to consistently achieve desired levels of destruction efficiency (DE) although industry spokesmen claim that incineration ships on and beyond the continental shelf destroy more than 99.99 percent of the chemicals they burn. The SAB also reported that research on environmental consequences of the process was limited and inconclusive. Of special concern was the failure of past research to fully characterize incinerator emissions, particularly with regard to products of incomplete combustion (new compounds formed in the combustion process). An assessment of environmental consequences focused on the initial impact of emissions on the microlayer or "surface skin" of the ocean—an environment that supports neuston (phytoplankton and zooplankton at the base of the marine food web)—which could have serious adverse effects all along the food web.

Although ocean incinerators may not operate as efficiently as their land counterparts* (see box and Figure 1), their emissions may present minimal risks to public health compared to land-based incineration since ocean

* Spokesmen for ocean incinerators claim destruction efficiencies of approximately 99.99 percent, whereas spokesmen for land-based incinerators claim 99.999999 percent destruction efficiency (Source: M.S. Connor, 1984, *Oceanus* 27(1): 70–74).

incineration is conducted more than 200 kilometers from the nearest population centers. However, because pollutants may drift back toward land and/or bioaccumulate in the food chain, the public health effects remain uncertain.

EPA's research protocol for a test burn was meant to answer some of the questions raised by the SAB. In particular, the research was to provide a better characterization of incinerator emissions and to test the toxicity of emissions on selected marine organisms.

Deficiencies in the research protocol was one factor that led to denial of the permit. Patrick M. Tobin, the Hearing Officer who presided over five public hearings on the permit and reviewed over 1,400 written comments submitted by the public, suggested that the use of PCB's for research purposes was inappropriate and attached an appendix of specific suggestions for improvement of the protocol. In addition, location of the burn at a site in the North Atlantic was seriously questioned because of its close proximity to the 106-mile dump site, making monitoring of environmental effects at the incineration site difficult if not impossible (Figure 2). On this basis, the Hearing Officer recommended completion of a qualitative assessment of synergistic effects of sludge dumping at the 106-mile dump site and the proposed incineration dump site to address this concern. Further, the Hearing Officer suggested that the Environmental Impact Statement (EIS) on the site be updated with new information that has become available since 1981.

Legal Issues

Ocean incineration activities are regulated under the London Dumping Convention (LDC) internationally, and in the United States, under the Marine Protection Research and Sanctuaries Act (MPRSA) (commonly known as the U.S. Ocean Dumping Act). Legally, ocean incineration is treated as ocean dumping—although most

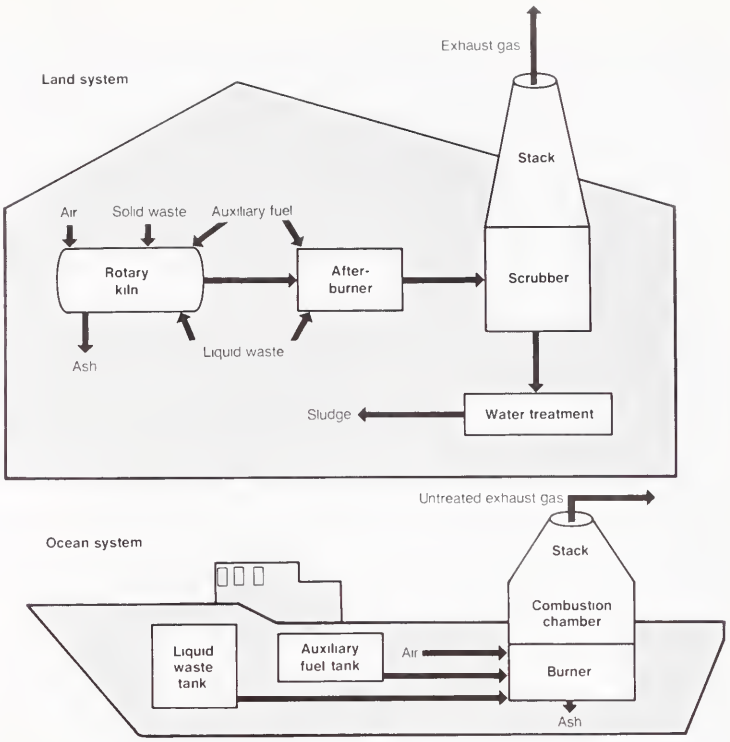


Figure 1. Ocean-based incinerators differ significantly from their land-based counterparts because of the absence of afterburners and scrubbers on the ocean-based incinerators. Afterburners act as a safety valve to guarantee complete destruction and scrubbers minimize air pollution by removing acidic gases and particulates from the stack emissions (reprinted with permission from Chemical and Engineering News, *Vol. 63, No. 49, p. 26).*

Ocean Incineration Technology

Presently existing ocean incinerators employ liquid injection incinerators mounted vertically onto a tank vessel. The combustion chambers are large vertically fired cylinders with a brief converging section that connects directly to the exit stack. After the incinerator is preheated with diesel fuel, liquid waste is injected into cylindrical combustion chambers lined with heat-resistant bricks. Gases from the vertical cylinders flow directly to the exhaust stacks. Ash is reincinerated or returned to land to be placed in a hazardous waste landfill. This design does not contain an afterburner or the pollution control equipment (scrubbers) required on most land-based incinerators (Figure 1). These characteristics, and also a shorter residence time of the wastes in the flame in ocean incinerators, make ocean incineration less efficient than land-based incineration.

Ocean incinerators have a capacity of approximately 724,000 gallons. For ocean incineration, only certain liquid wastes are suitable. These include certain commercial chemical product wastes, ignitable wastes, and solvents. Although ocean incineration ships have three times the annual capacity of most land-based incinerators, because ocean incinerators can only deal with about 8 percent of all hazardous wastes generated each year, the technology has the potential to address only a small part of the hazardous waste management dilemma we currently face.

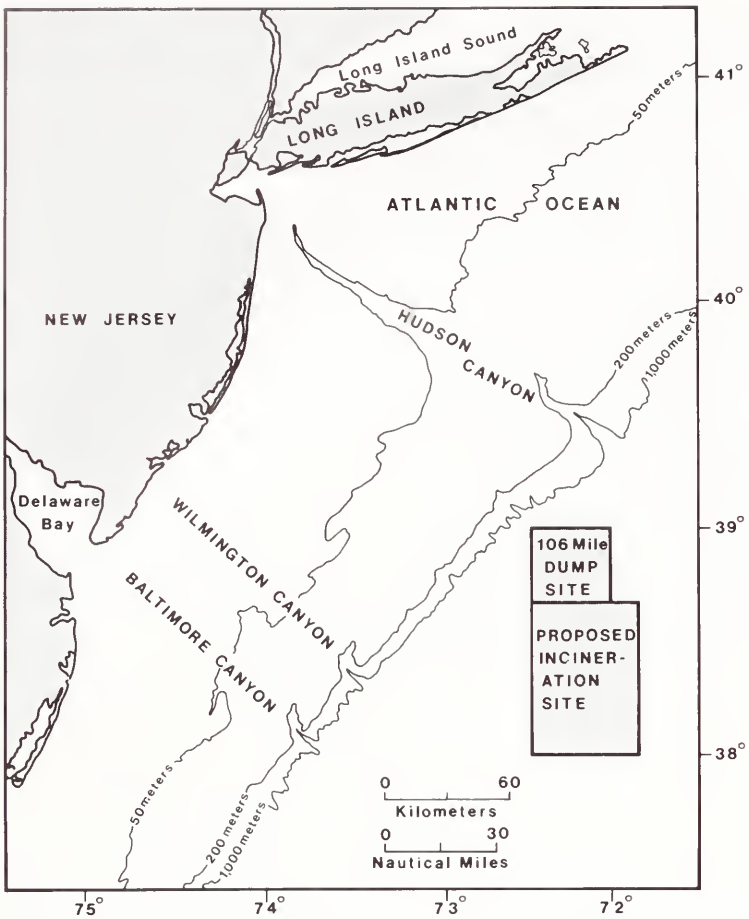


Figure 2. The close proximity of the 106-mile Dumpsite to the proposed ocean incineration site in the North Atlantic would make monitoring and surveillance of potential environmental impacts from incineration activities difficult, if not impossible. (From U.S. EPA, "Environmental Impact Statement for the North Atlantic Incineration Site Designation," December, 1981)

of the waste is destroyed, waste emissions are dumped into the air and sea.

Several important legal issues emerged under these and other laws, in addition to criticisms of the research protocol itself, that would have left the permit, if issued, open to legal challenge. The question of who will pay in the event of an accident involving an ocean incinerator is not clear under existing law. And EPA's suggestion that the permit applicant demonstrate financial responsibility in the amount of $60 million was met with a hue and cry from industry, contending that EPA has no legal authority to impose such requirements. Proposed amendments to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), commonly known as Superfund, attempt to clarify the law, but the adoption of these amendments is uncertain.

Another major legal issue raised with regard to the permit concerns the requirement that the "need" for the dumping (incineration) activity be demonstrated prior to issuance of a permit. Presently in the United States, such a permit will be issued only upon demonstration that no improvements can be made in process technology to reduce adverse impacts and that there are no practical alternative locations and methods of waste disposal or recycling.

These and other legal issues were recommended for further review. EPA's decision particularly emphasized the need to resolve the liability and financial responsibility issue. Presumably this should be done prior to the issuance of any permits by EPA.

Promulgation of Draft Regs

EPA's decision on the proposed permit expressed the view that most of the questions raised by the public could be addressed in the context of promulgation of revised draft regulations. In February, 1985, EPA issued draft ocean incineration regulations, and solicited public comment. These regulations were never finalized. Now EPA wants to go back and further revise those regulations to be issued once again in draft form.

The Agency may now find itself in a Catch-22 situation. On the one hand, EPA has expressed the view that it will issue no permits until regulations have been promulgated. However, without conducting necessary research it will be difficult for the Agency to develop appropriate performance standards and environmental criteria. Based on recommendations by the Hearing Officer, the Agency has indicated that it will at least consider some land-based research prior to promulgation of regulations. Such research is necessary if the regulations are to provide sound scientific and technical requirements.

Further, both the Hearing Officer's Report and EPA's final decision stressed the need for the Agency to institute more meaningful opportunities for public participation in the regulatory process. Recognizing the Agency's failure to foster public support for this program, the Hearing Officer suggested that EPA form local advisory committees to review permit applications and make recommendations.

The Agency does not expect to issue revised draft regulations until well into the Fall. Moreover, if EPA follows the recommendations of the Hearing Officer by conducting

necessary research and providing public input into the process, this issuance might not occur until sometime next year. It could be 1988 before finalization of the regulations. Until regulations are final, the United States will issue no permits for ocean incineration.

International Outlook

EPA's recent decision makes it highly unlikely that any ocean incineration permits will be issued by the United States for several years. The question arises as to what, if any, influence the U.S. decision will have on continued use of this technology abroad. European nations have been incinerating hazardous waste in the North Sea since 1969. Although the LDC regulates the activity internationally, the Oslo Convention regulates ocean incineration on a regional basis in the North Sea. Under both of these agreements, ocean incineration is considered an "interim" measure, pending development of better solutions to hazardous waste management and subject to results of research on its effectiveness. In accordance with this view, movement is under way within Europe to terminate the use of ocean dumping in general, including ocean incineration.

Last year, based on the SAB Report, international scientists agreed that certain scientific and technical questions about the technology warranted further consideration. The LDC decided to convene a group of experts to take a closer look at these questions and to make recommendations concerning possible revision of LDC incineration regulations. Terms of reference for the review have already been developed. However, it was assumed that the review would take place after the United States had conducted its research burn, since the results of that burn were expected to provide more insight into the issues of concern. In the absence of a research burn by the United States or another member party to the LDC, it is possible that the group of experts meeting will be delayed. In the meantime, parties continue to conduct incineration activities under existing LDC regulations.

Under the Oslo Convention, a regional convention that regulates incineration activities in the North Sea, the parties have agreed to meet by January 1, 1990 to determine a date for terminating the use of this technology. Many European nations wish to put an end to ocean dumping of hazardous substances. As a result, the Commission of the European Communities has made a proposal to the Council of Ministers of the European Economic Community (EEC) that would gradually phase out the use of ocean dumping and ocean incineration.

Under Article 9 of that proposal, member states are directed to "promote the development of alternative land-based methods of disposal, ... endeavor to reduce the quantity of waste and encourage its recycling through the use of appropriate techniques before considering its dumping or incineration at sea." To that end, the proposal would prohibit the issuance of new dumping or incineration permits by January 1, 1988; existing dumping or incineration permits could be renewed only until January 1, 1990; over a period of five consecutive years from January 1, 1990, member states would be required to reduce their waste by 10 percent each year; and a date for termination of ocean incineration would be agreed to by June 1, 1991.

OTA Report Lists Burn Options

Burning hazardous wastes in incinerators mounted on ocean-going vessels could be an attractive, though not essential, interim option for managing certain liquid wastes, according to a report released in mid-August of this year by the Congressional Office of Technology Assessment (OTA).

Several waste treatment methods, such as ocean incineration, will be needed to bridge the gap between hazardous waste disposal practices of the past (such as landfilling), which are being abandoned, and preferred practices of the future (such as waste reduction), whose capacity is only now developing, according to OTA.

Ocean incineration, the report stated, may be particularly useful for wastes that are highly chlorinated. Burning these wastes generates an additional product, toxic hydrogen chloride gas. To prevent human exposure to this gas, land-based incinerators must neutralize it using a difficult "scrubbing" process which in itself generates hazardous waste. Ocean incineration, occurring far from humans, would use seawater's natural ability to neutralize the gas.

Of the 250 million metric tons of hazardous waste generated annually in the United States, up to 20 percent, in principle, could be incinerated. Up to half that fraction—organic liquids— could be incinerated at sea. These are among the most toxic and concentrated of hazardous wastes. Today, as much as 65 percent of the organic wastes are disposed of on land or used as fuel in boilers and furnaces. Only small amounts are now incinerated, all on land. The United States has temporarily halted the use of ocean incineration, mostly in response to public concerns.

Copies of the report, Ocean Incineration: Its Role in Managing Hazardous Waste, *are available from the U.S. Government Printing Office (GPO), Superintendent of Documents, Washington, D.C. 20402, phone (202) 783-3238. The price is $11.00.*

Despite the apparent desire of many European nations to terminate the use of ocean dumping and ocean incineration, an application has been made to the Netherlands government for a permit to conduct a burn of PCB's in the North Sea. Under the Oslo Convention, such a permit is subject to prior consultation, where all contracting parties review the permit and may veto its issuance. At a March meeting of SACSA (a scientific subcommittee of the Oslo Convention), it was reported that most of the contracting parties opposed even an experimental burn of PCB's.

Although they have had more than a decade of experience with ocean incineration, the recent U.S. decision is of interest to European policymakers and scientists. National authorities and participants in the LDC are eager to see how the United States resolves the important questions raised about the effectiveness of the technology and its environmental impacts. In the face of scientific and technical uncertainty, and given the general desire to abandon ocean dumping (including ocean incineration) for environmentally preferable alternatives, continued use of this technology in Europe in the long term is questionable.

Conclusion

EPA's recent decision may have effectively closed the door on the use of ocean incineration in the United States (at least for the short term). At the same time, without resolution of scientific and technical uncertainties, the United States, and Europe as well, will be further encouraged to pursue other options. Putting the ice on ocean incineration may provide the needed incentive for more promising technologies to step in to fill the gap.

Sally Ann Lentz is Staff Attorney of The Oceanic Society in Washington, D.C. Clifton E. Curtis is President of The Oceanic Society.

California Oil Case Tests State-Federal Coastal Role

by Timothy Eichenberg

Exploiting our nation's offshore energy resources involves tremendous economic and environmental stakes. It has prompted the growth of a complicated web of often conflicting legislation and judicial decisions, and launched a major state-federal conflict over the right to regulate activities affecting coastal resources.

A recent Federal District Court decision in Los Angeles (*Exxon v. Fischer*, Civil No. 84-2362, October 11, 1985), has altered the relationship between the federally-regulated outer continental shelf (OCS)* oil and gas development, and state concerns. It has prompted the White House to issue a directive (June 6, 1986) to Secretary of Commerce Malcolm Baldrige to examine state coastal management policies to determine how the "national interest in energy security" can be advanced.

The Department of the Interior's oil and gas leasing program generated $7.5 billion in federal revenues last year, and has produced $76 billion since its inception in 1953. This makes it one of the largest single sources of federal revenue other than income and social security taxes. Moreover, offshore oil and gas production reduces U.S. dependence on foreign oil, and thereby eases certain national security concerns, as well as helping our balance of payments.

But oil and gas development offshore also involves certain environmental risks and impacts; oil spills, air emissions, and operating discharges from offshore development may affect public

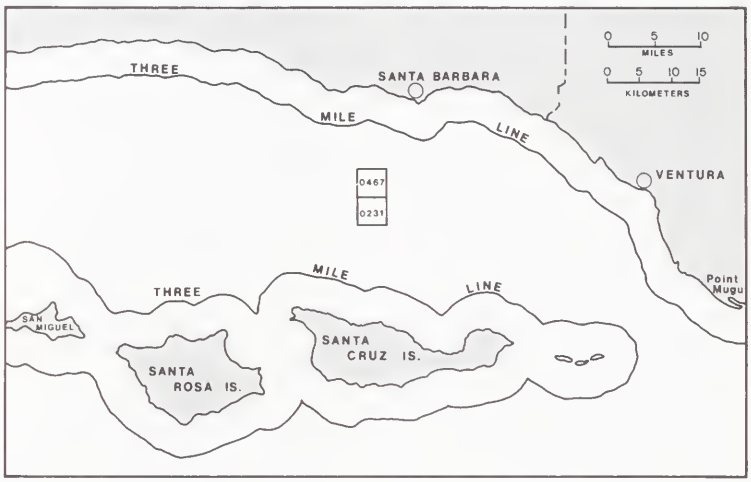


Figure 1. Site of Exxon proposed exploratory drilling in the Santa Barbara Channel, on Tract No. 467.

health, local seabirds, shorebirds, fisheries, recreation, and aesthetics. These are concerns primarily expressed at the state level. Therefore there has been a continuing debate over how much control states should have over federal offshore oil leasing, exploration, and production.

The controversy during the last several years has centered on the role of the states in the federal OCS leasing program, where tracts, consisting of 9-square-mile blocks, are leased to the highest bidder by the Department of the Interior. But *Exxon v. Fischer* moves the debate from the leasing stage to the post-leasing exploration, development, and production phases, where the actual physical impacts of oil and gas development occur.* The principles involved in this case are likely to affect the way in which government regulates other important offshore activities, such as commercial fishing operations, ocean dumping, the incineration of waste materials, deep seabed mining, commercial shipping and transportation, tourism, and the recreational use of our coastal offshore waters.

Traditional Alliances and Partnerships

In order to appreciate the significance of *Exxon v. Fisher*, it is important to understand the context in which it was decided. The history of the development of offshore resources has fostered some traditional alliances and partnerships. The Department of the Interior and the oil industry have traditionally sought to impose broad, federally-

* The OCS is generally defined as the submerged lands and waters beyond those granted to the states under the Submerged Lands Act of 1953. State coastal waters or the waters of the coastal zone in most cases extend up to 3 miles offshore.

* Exploration involves exploring for commercial quantities of crude oil and gas with mobile drilling rigs. Development and production involve the construction of semipermanent offshore platforms from which as many as 80 production wells can be drilled. The product is then treated and transported to refining destinations by pipelines or ships.

dominated, and development-oriented policies on the OCS energy program. On the other hand, Congress and the states have generally resisted by pursuing legislation to extend state jurisdiction and mandate local participation in the decision-making process. The various groups involved have not hesitated to resort to litigation and the courts have generally supported the broader, federal approach.

These historic rivalries first became apparent in 1947, when the United States Supreme Court conferred exclusive jurisdiction over all U.S. offshore lands and water, and the resources thereof, to the federal government in *U.S. v. California* (332 US 19, 1947). Rising to the challenge, Congress, six years later returned all federal interest in submerged lands, up to three miles offshore, to the states through the Submerged Lands Act (43 USC 1311).

In 1969, the Presidentially-appointed Stratton Commission recommended that states be the "focus for responsibility and action in the coastal zone." Congress responded by enacting the Coastal Zone Management Act of 1972 (CZMA, 16 USC 1451 et. seq.), establishing a state-federal "partnership" whereby federal assistance was provided through the National Oceanic and Atmospheric Administration (NOAA), within the Department of Commerce, to help develop and implement state coastal management programs (CMPs). Once a state's CMP was approved by NOAA, that state became empowered with "federal consistency" authority to review "federal activities," licenses, and permits, affecting the coastal zone, for consistency with the federally approved CMP.

The Arab oil embargo and resulting energy crisis led to the 1976 CZMA amendments expanding state consistency review authority over OCS oil and gas exploration, and development and production plans, issued by the Department of Interior. The environmental consequences of expanded offshore development caused by the national effort to become energy independent would fall most heavily on the coastal states. Therefore they were given a larger policy role on the OCS by Congress.

State Review of Lease Sales

It was widely believed that the term "federal activities" in the CZMA included Interior's OCS oil and gas leasing program. In fact, in 1983, 28 state consistency determinations were rendered for federal lease sales under these provisions. But in 1984, the Supreme Court ruled that Interior's leasing program did not "directly affect" state coastal zones and therefore lease sales were not subject to state review under the federal consistency provisions of the CZMA (*Secretary of Interior v. California*, 104 S.Ct. 656, 1984). As a result, states must now confine consistency reviews to individual exploration and development plans.

But review at these latter stages is extremely difficult because of the huge sums invested by oil companies in obtaining leases from the Department of the Interior. In the Santa Barbara Channel during the 1970s, Chevron paid a record $333 million for lease tract OCS P-0450, a three-mile by three-mile tract on the OCS. Other nearby leases were obtained for bids of $208 million, $163 million, and $81 million. Obviously, after such an investment, it is very difficult to tell these companies they cannot explore or develop their lease tract.

Congress also has attempted, albeit unsuccessfully to date, to overturn the *Interior v. California* holding by amending the CZMA to specifically require that lease sales be reviewed by states for consistency with their coastal management program policies. However, the threat of a Presidential veto and obstacles to reauthorization of the federal coastal management program itself, has thus far discouraged amendments to the consistency provisions of the CZMA. In response to this and other failures to address state concerns with the federal OCS leasing program, Congress has removed more than 52 million acres from potential development since 1982 by placing a moratorium on the Department of the Interior's budget appropriations.

The "partnership principle" espoused by Congress in the CZMA was also the impetus behind the 1978 amendments to the Outer Continental Shelf Lands Act (OCSLA). The amendments require the Secretary of Interior to consider state non-binding recommendations on the size, timing, and location of OCS lease sales and development and production plans, and also require Interior to receive state consistency concurrences prior to approving any exploration and development plans.

Many other legislative initiatives promote the partnership principle in marine resource management. For example, the Fishery Conservation and Management Act creates joint state/federal Fishery Management Councils to manage OCS fishery resources. The National Environmental Protection Act calls for state and local participation in the development of Environmental Impact Statements (EISs) to guide major federal actions, including federal OCS lease sales and development and production plans. The Marine Protection, Research, and Sanctuaries Act requires state participation prior to the designation of national marine sanctuaries. But this principle (state and federal partnership) is now under attack.

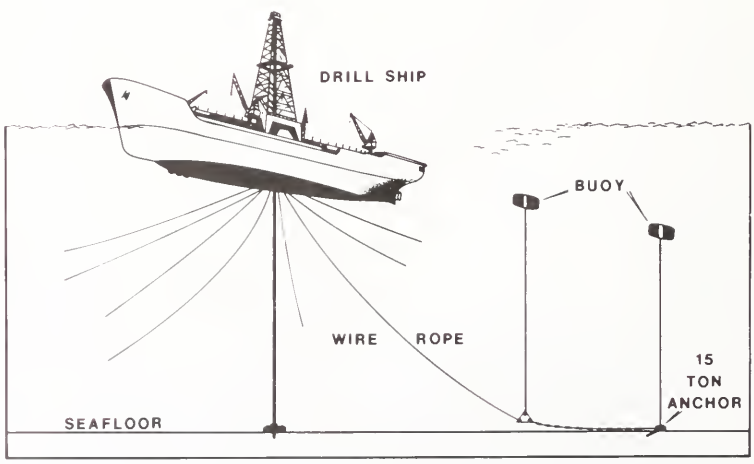


Figure 2. Conflicts in the use of ocean space arise from requirements of drill ships, with their complex anchoring and buoyage systems, and

The Case and Controversy

Exxon v. Fischer pits the world's largest oil company* against the State of California, in a case that has widespread implications for OCS oil and gas development. Michael L. Fischer was the Executive Director of the California Coastal Commission, an independent state agency delegated under the CZMA to implement the California Coastal Management Program (CCMP). California refused to certify that Exxon's proposal to drill an exploratory well in the Santa Barbara Channel (see Figure 1) was consistent with state CMP policies protecting commercial fisheries. The Commission found that the drilling operations would conflict with drift-net fishing for thresher shark in the Channel in an especially productive area. The drilling vessel and anchor chains were believed to create hazards for the drift-netters, who were in fear of tearing their costly, mile-long nets (Figure 2). It takes up to 15 hours for such fishermen to haul in their nets, during which time they are unable to maneuver adequately to avoid hazards.

Consequently the State prohibited drilling during the thresher shark season, but allowed a "drilling window" from Thanksgiving to May, when it would not conflict with commercial fishing operations. Exxon refused to accept a seasonal limitation on its drilling activities, claiming that the State was without authority to reduce the federal five-year lease period. Exxon also denied that its exploratory operations substantially interfered with drift-net fishing, disputed the fishermen's claim that the area was a productive fishery, and argued that domestic energy policy dictated priority for oil and gas exploration.

Exxon, with strong support from the Department of the Interior, appealed California's action to the Secretary of Commerce. Under the CZMA, an objection may be appealed to the Secretary on the grounds that it is "consistent with the objectives or purposes of the Act" or "necessary in the interest of national security." NOAA regulations further define these standards, providing that in order to override a state's objection the Secretary must find that the OCS activity satisfies *all* of the following standards:

- It furthers one or more of the national objectives of the CZMA found in Sections 302 or 303 (16 USC 1451 and 1452).
- It does not cause separate or cumulative adverse impacts substantial enough to outweigh its contributions to the national interest.
- It does not violate the Clean Air Act or Clean Water Act.
- There are no reasonable alternatives available so that it can be conducted consistent with the state management program.

However, even if the Secretary is unable to make these findings, an objection can still be overridden if it can be shown that "a national defense or other national security interest would be substantially impaired" or the activity "directly supports national defense or other national security objectives."

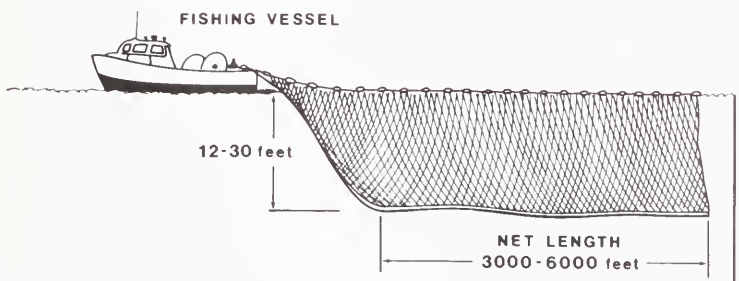
After holding a public hearing and analyzing the claims of the various parties in terms of these criteria, on 14 November 1984, the Secretary of Commerce sustained California's objection to Exxon's drilling plan. The Secretary held that the national interest in exploring for domestic energy resources outweighed the adverse impacts on the fishing industry. Nevertheless, he upheld the objection because he found that there was a reasonable alternative available: Exxon could simply conduct its exploratory activities during the November to May "drilling window" without incurring unreasonable delays or undue financial hardships.

Exxon could have challenged the Secretary's decision, but it was well-reasoned and unlikely to be overruled. Therefore, Exxon pursued a federal court action against California, alleging that the State lacked the authority under the CZMA to object to Exxon's drilling operations. The basis of their case was that Exxon's drilling operations were proposed on the OCS, beyond the three mile state coastal boundary, and therefore did not affect any land or water uses in the coastal zone. Exxon argued that while some adverse "economic" impacts on the State's fishing industry might occur, the CZMA was not intended to protect economic concerns. This view also was strongly supported by the Department of the Interior.

Exxon's views were adopted by Federal District Court Judge Pamela Ann Rymer on all counts. She agreed that the only impacts that occurred in the coastal zone were economic and that there was no evidence that there were any effects on the "natural resources" of the coastal zone. Judge Rymer therefore concluded that:

> The CZMA's statutory language and purpose as well as its

* Since 1974, Exxon was the largest company in the world. But in 1985, General Motors reported earnings of more than $96 billion, exceeding Exxon's revenues of $93 billion.



fishermen, whose mile-long nets impose limited maneuverability.

> legislative history lead to the conclusion that (it) does not authorize the Commission to object to activities affecting the harvesting of marine resources which are located outside of the coastal zone.

The California Coastal Commission immediately ordered that an appeal of the decision be filed with the 9th Circuit Court of Appeals. The appeal has not yet been decided.

Future Marine Policy Impacts

Although the legal effect of a Federal District Court opinion is limited, the dynamics of the existing political climate and the broad nature of the marine policy issues involved in *Exxon v. Fischer* are likely to have legal, political, and policy implications that reach beyond mere legal precedent. As noted earlier, Congress has been, and remains today, actively involved in attempting to create a larger state role in the implementation of federal OCS policies. If this case is upheld on appeal, Congress may be inclined to take corrective measures similar to those initiated after the Supreme Court decisions in *U.S. v. California* and *Secretary of Interior v. California*, to enable states to protect their commercial fishing industry from the effects of offshore oil development.

The finding in *Exxon v. Fischer*, that the CZMA was not intended to protect state economic interests, will be particularly difficult for state and local representatives to accept in view of express statements of legislative intent in the CZMA to, "encourage and assist the states to exercise effectively their responsibilities in the coastal zone . . . giving full consideration to ecological, cultural, historic and aesthetic values as well as to needs for *economic development* . . ." (16 USC 1452(2), emphasis added). Other sections of the CZMA refer to the "commercial" resources, "expanding demands for food," and protecting the "industry and commerce" of the coastal zone. It will be interesting to observe what the Congressional response will be to an opinion that ignores this mandate.

The legal issues presented by *Exxon v. Fischer* also present intriguing marine policy questions. To a large extent, the U.S. Supreme Court based its holding in *Interior v. California*—that federal lease sales are not subject to state consistency review—on the belief that states retain considerable "veto authority" when they subsequently review OCS oil and gas exploration and development under the CZMA. For this reason the Court found state review at the leasing stage redundant.

But *Exxon v. Fischer* undermines this rationale and limits the kinds of state coastal management policies that can be applied to OCS oil and gas development. If state commercial fishing policies are found to be inapplicable, then other state policies, such as those regulating air quality impacts, the discharge of muds and cuttings, pipeline preferences, and visual and recreational concerns, may also be deemed inapplicable. Because the Supreme Court relied on a significant state role in reviewing OCS exploration and development, it may be reluctant to further diminish that role in *Exxon v. Fischer*.

Finally, *Exxon v. Fischer* is likely to affect the entire administrative appeal process established under the CZMA. In all, 17 appeals from state objections have been filed with the Secretary of Commerce and six decisions have been rendered. The regulations cited earlier show that complex issues of fact and law must be analyzed. Several of the appeals contained administrative records that exceeded 20 volumes, containing tens of thousands of pages. Extensive local public hearings have been held and the Secretary has solicited and considered the advice of numerous federal agencies on the national interest and security issues. The decisions rendered by the Secretary have been thorough and well-reasoned and despite their controversial nature, have not been overturned or judicially challenged to date.

The Secretary's decision, to uphold California's objection, had little substantive impact on the legal reasoning or outcome of *Exxon v. Fischer*. California argued that Exxon should have sued the Commerce Department, not the State, because the Secretary's decision was the final administrative decision. Although the Secretary specifically found that Exxon's project would have effects on the coastal zone, and that Exxon's economic injury from using the "drilling window" would be slight, Judge Rymer ignored the Secretary's finding on these points. She ruled that the Secretary was not legally empowered to address the coastal zone impacts of conflicts between the oil and fishing industries on the OCS. This relegates the Secretarial appeal process established by Congress and the Department of Commerce to a relatively minor role and questions the efficacy of the entire CZMA appellate mechanism, which was established to resolve state, federal, and industry marine policy conflicts.

The ultimate impact of *Exxon v. Fischer* will not be known until the case is decided on appeal and, because of the significant issues involved, a request for a U.S. Supreme Court hearing is likely. The case has already been cited by Department of Interior officials who would like to see NOAA's federal consistency regulations substantially changed to facilitate offshore oil and gas development, and it is likely that the White House had *Exxon v. Fischer* in mind when it directed Commerce Secretary Baldrige to, "use his regulatory authority to minimize the overlap in judicial and administrative jurisdiction over coastal zone practices."

Significant inroads have already been made in the ability of states to influence decisions affecting their coastal waters. If the Supreme Court decides to further restrict state consistency authority, and uphold *Exxon v. Fischer*, or if the implementation of state coastal management authority is administratively weakened by the President or his cabinet, Congress will again be urged to take action to protect state interests. More conflicts over the management of ocean and coastal resources therefore seems likely.

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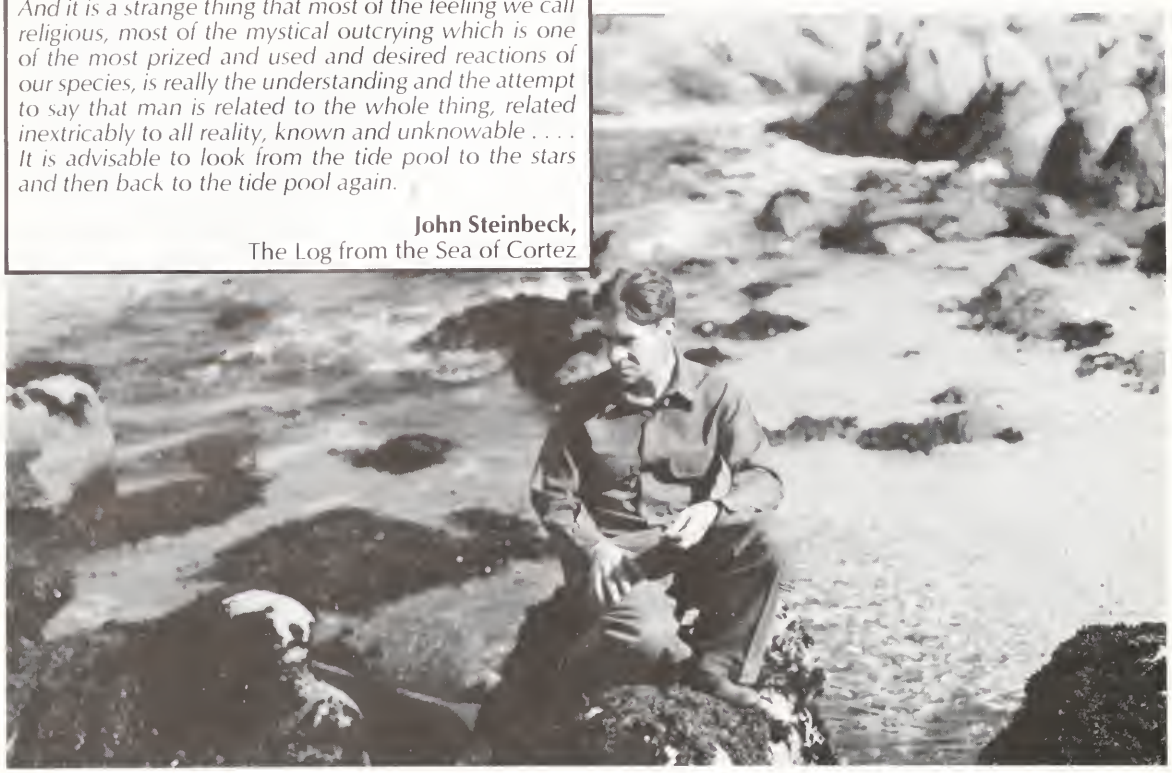
Acknowledgments

Research supported by the J.N. Pew, Jr. Charitable Trust, and the Marine Policy and Ocean Management Center of the Woods Hole Oceanographic Institution.

And it is a strange thing that most of the feeling we call religious, most of the mystical outcrying which is one of the most prized and used and desired reactions of our species, is really the understanding and the attempt to say that man is related to the whole thing, related inextricably to all reality, known and unknowable . . . . It is advisable to look from the tide pool to the stars and then back to the tide pool again.

John Steinbeck,
The Log from the Sea of Cortez



Steinbeck and Ricketts: Fishing in the Mind

by Bruce Finson and Katherine E. Taylor

EDITOR'S NOTE: The following article contains material that first appeared in 1982 under Mr. Finson's byline. That material has been reworked and added to by Ms. Taylor. It is printed with permission from *Pacific Discovery*, the journal of the California Academy of Sciences.

Ed Ricketts, who worked out of Monterey, California, in the late 1930s and 1940s, was the guiding light for a whole generation of marine biologists, those who were the "hip-boot" or "tide-pool" scientists. Moreover, the collaboration of biologist Ed Ricketts and writer John Steinbeck led to a view of biology and life rarely found in either art or science.

Most people who have read John Steinbeck know that a biologist named Ed Ricketts was the model for the character "Doc" of *Cannery Row* and *Sweet Thursday*. What they do not know is that the friendship between John Steinbeck and Edward F. Ricketts was one of the pivotal relationships in the life and work of both biologist and novelist. *The Outer Shores*, a two-volume paperback book written and edited by biologist Joel Hedgpeth, who knew both men well, makes this clear. The book is about and by Ed Ricketts, and includes biological and philosophical papers by him and also his expedition logs, as well as Hedgpeth's biographical commentary, discussion of the included papers, and

Above, Ed Ricketts among the tide pools, 1947. (The Pat Hathaway Collection)

Cannery Row, 1947, setting for John Steinbeck's book of the same name, and home of Ed Ricketts. (The Pat Hathaway Collection)

an analysis of the Ricketts-Steinbeck relationship.

Not only were Ricketts and Steinbeck close friends for more than 20 years, but Steinbeck was also a partner in Ricketts' business, Pacific Biological Laboratories. Steinbeck had studied biology, and was considered by Ricketts to be a good field man. Ricketts had studied poetry and music, and he wrote some highly original philosophical essays. The two men collaborated on major biological expeditions, and on a science-and-travel book. Ricketts had already collaborated with Jack Calvin, on a trend-setting, ecologically-oriented invertebrate field text, *Between Pacific Tides*.

Sea of Cortez Expedition

But the high point of Ricketts' writing career, and of his two cultures collaboration with Steinbeck, was a collecting expedition he made to the Gulf of California, also known as the Sea of Cortez, in the spring of 1940. On a small fishing boat, the *Western Flyer*, they spent six weeks with a small crew in the Gulf, where they collected more than 550 species of marine invertebrates. They also soaked up the atmosphere of the then remote Baja California villages, ate fish and lobster and more fish, discussed philosophy-science-art-music-love, and comprehensively taste-tested the local Mexican brews. All the while keeping up the grueling work of collecting, preserving, identifying, and labeling the biological specimens available at several dozen intertidal collecting stations. The result of this joint venture in unified field living was their most extraordinary book, *Sea of Cortez, a Leisurely Journal of Travel and Research*.

Cannery Row as viewed from Monterey Bay. (The Pat Hathaway Collection)

The Western Flyer, *1940, on which Ed Ricketts and John Steinbeck made their famous Sea of Cortez expedition. (The Pat Hathaway Collection)*

The Log from the Sea of Cortez

The book contains an unhurried personal narrative of the expedition, and a detailed phyletic catalog of the specimens. Although Ricketts and Steinbeck are listed as co-authors, when the book was published, in 1941, reviewers and critics immediately assumed that the narrative was written solely by Steinbeck, and the catalog solely by Ricketts. This is not so. The book was a thoroughgoing collaboration. And it was only with the appearance of Hedgpeth's *The Outer Shores* that the evidence for this conclusion has become publicly available.

Ricketts kept a log of the expedition, and of course the collecting notes. Steinbeck used them as the basis for the narrative text of the book, which closely parallels the log. While Steinbeck was writing up the narrative, expanding on Ricketts' tersely objective notations, and transforming remembered atmosphere into evocative prose while maintaining the sequence and much of the original material of the log, Ricketts was translating the collecting notes, based on both men's independent studies, into the phyletic catalog of the invertebrates of the Gulf. Ricketts also wrote up the results of their informal shipboard seminars and earlier discussions, in the "Essay on Non-Teleological Thinking." This essay appeared, hardly mofified, in *Sea of Cortez*, and is now published, exactly as Ricketts wrote it, in *The Outer Shores*. Both the log and the narrative make it clear that Steinbeck participated extensively in the collecting, studying, and preserving of the Gulf invertebrates. Steinbeck, in answer to a naive question about his profession, is quoted as having once replied, "Well, you might say I am a sort of biologist."

A Blending of Two Approaches

One intent of *Sea of Cortez*, as made clear by Ricketts in an essay in *The Outer Shores*, was to reblend the scientific and artistic views of nature into the original whole from which the specialists had separated them. In the introduction to *Sea of Cortez*, Ricketts and Steinbeck comment: "We wanted to see everything our eyes could accommodate, to think that we could, and, out of our seeing and thinking, to build some kind of structure in modeled imitation of reality." Also, "We determined to go doubly open so that in the end we could, if we wished, describe the sierra thus: 'D.XV11-15-X; A.11-15-X,' but also we could see the fish alive and swimming, feel it plunge against the line, drag it threshing over the rail, and even finally eat it." And they conclude: "Perhaps out of the two approaches, we thought, there might emerge a picture more complete and even more accurate than either alone could produce. And so we went." Joel Hedgpeth writes in *The Outer Shores*, that many who knew the two authors, "recognized the fundamental unity of *Sea of Cortez* and its relation to Ed's 'holism,' that bringing together of all threads of thought and experience."

It is clear, from a study of the log and the narrative together, the other writings by both authors, and the biographical commentary by Hedgpeth, that the friendship and collaboration between Steinbeck and Ricketts profoundly influenced both of them. Hedgpeth has done the still-too-separate worlds of science and art an excellent service in bringing together the Ricketts papers, and in performing the literary, biological, and biographical research necessary to provide a rounded picture of the complex and original mind and personality of Edward F. Ricketts. Hedgpeth makes it clear that Ricketts, an independent biologist and owner of a biological supply house, who did not even have a college degree in the field, was a biologist ahead of his time. He looked at life from a unified, ecological viewpoint which was rare in a

profession at that time committed to taxonomic analysis.

Ricketts' advanced views delayed the publication of his still-important field-text, *Between Pacific Tides*, for a number of years. To him, the whole situation of the community of organisms in relation to its environment was the important thing to understand. As Steinbeck wrote, "His scientific interest was essentially ecological and holistic. His mind always tried to enlarge the smallest picture." At the same time, he never neglected the all-important work of identifying and classifying the animals he collected in the course of his combined work of adding to his inventory and observing ecological relationships.

Popularization and Communication

Through their writings and personalities, Ricketts and Steinbeck helped make the study of marine biology popular. As Hedgpeth pointed out in *The Outer Shores*, Steinbeck's portrait of Ed Ricketts as 'Doc' in *Cannery Row*, is the only full treatment of a marine biologist in English fiction. *Between Pacific Tides*, one of the classic works of marine biology, has remained extremely popular for many reasons, one of which is, as Hedgpeth wrote in the preface to the fourth edition of the book, "that people want to know about seashore animals, and no one else has presented the information in terms of the way of life—the ecology, if you will—of the seashore in such a readable manner."

Communication of biological concepts to all types of readers was important to Ricketts and Steinbeck, and consistent with Ed's desire for a blending of the too-separate worlds of science and humanitites, for only if all people are able to read and understand science, will that integration occur. Steinbeck and Ricketts wrote in *Sea of Cortez*, "It is usually found that only the little stuffy men object to what is called 'popularization,' by which they mean writing with a clarity understandable to one not familiar with the tricks and codes of the cult. We have not known a single great scientist who could not discourse freely and interestingly with a child. Can it be that the haters of clarity have nothing to say, have observed nothing, have no clear picture of even their own fields?"

Ricketts knew that his work with Steinbeck was important and unique. In a letter to Steinbeck a year after their return from the Sea of Cortez, Ricketts writes, "It would be an understatement for me to say that this little trip of ours is going to be an important expedition, and that out of it are coming some fairly significant contributions to invertebrate zoology, to marine sociology, and even—I wouldn't be surprised—to human thought."

Ricketts as Philosopher

The Ricketts papers also show him as a philosopher—not as an organized fabricator of conceptual systems, but as a commentator on ideas and their implications. In addition to the "Essay on Non-teleological Thinking," which Ricketts in a separate essay shows to be central to the structure of *Sea of Cortez*, there are essays on "Nostalgia," "The Philosophy of 'Breaking Through,'" and "The Spiritual Morphology of Poetry." All four essays circulate around a common theme; those moments that a recent philosophical psychologist, Abraham Maslow, has called "Peak Experience." Such a theme might seem far removed from the study of wildlife, but Ricketts saw a relationship.

John Steinbeck, friend of Ed Ricketts and Nobel Prize winning author of Cannery Row, The Grapes of Wrath, Of Mice and Men, *and many other books. (Photo courtesy of UPI/Bettman Newsphotos)*

As a biologist, he was keenly concerned not merely with the ecological approach, but also with the larger implications of such an approach. In a way that is difficult to state except by analogy because our language has no simple terms for these concepts, Ricketts saw that there were aspects of any biological community that could not be accounted for, or defined on, the scale of the individuals composing it, just as one cannot explain the life of an individual organism on the scale of the cells composing it. Ricketts' ideas about biology parallel the doctrines of vitalism and organicism, which state that the functions of a living organism are due to a vital principle, and that life and living processes are the manifestation of an activity possible only in virtue of the state of autonomous organization of the system rather than because of its individual components. Ricketts saw the intuitive leap toward a higher understanding of the community as a whole as a peak experience—which might be defined as a

Ed Ricketts' lab at 800 Cannery Row, 1948. (The Pat Hathaway Collection).

charged combination of feeling/knowledge and concept/knowledge.

Hedgpeth comments that Ricketts "wanted to bring together within himself all the different things and ideas which interested him to produce his own personal synthesis." Writing philosophical essays was his way of synthesizing his biological knowledge with his other ideas into a unique vision of the world.

Science and Art

Ricketts was able to find the expression of this super-integrative level more in the realm of art than in science. In certain pieces of music and poetry, he felt there was an attempt, never totally successful, to represent those special moments when perception transcends the ordinary. At such moments we see, in the world and in ourselves, what presents itself as a more comprehensive integration, accompanied by a particular kind of intensity, not of ordinary emotion, but perhaps of inner feeling. Scientists as well as artists have commented that their most creative discoveries arrive at such moments.

These moments of enhanced understanding in any realm, artistic or scientific or personal, Ricketts called "Breaking Through." His essay on that subject sums up important references from earlier writers on this subject, and presages the resurgence of this theme in some modern schools of thought. He summed up this whole inner movement of perception quite precisely, when he spoke of "Achieving things which are not transient by means of things that are." *The Outer Shores* notes that "Ed's philosophical ideas have become widely popular among readers who never read formal philosophy because Steinbeck took them over and blended them with his considerable literary skill into *Sea of Cortez*."

Ricketts saw Steinbeck as a great artist, and he reflected on his literary skill, in a letter to a friend, Toni Jackson, "I have just been reading what John wrote today. It's so damn beautiful I can hardly stand it. He takes my words and gives them a little twist, and puts in some of his own beauty of concept and expression and the whole thing is so lovely you can't stand it."

After Ricketts' Death

Since Ricketts' death, in 1948, his notebooks and collections have had separate histories. The Sea of Cortez specimens that Ricketts and Steinbeck collected, first took their place among the other important biological collections of the Hopkins Marine Station, including collections by Luis and Alexander Agassiz, William Beebe, Carl Hubbs, and almost every other major marine biologist of the time. Later when the emphasis in university biology changed from field to laboratory work, the Hopkins collections were deposited at the California Academy of Sciences. Some of the material from the notebooks was used in studies of Steinbeck and Ricketts by Richard Astro, Betty Perez, and others, but most of the writings did not reach an audience until Hedgpeth assembled them for publication.

Ed Ricketts and his friend Ritchie Lovejoy working in Ed's laboratory in the late 1930s. (The Pat Hathaway Collection)

The creative-integrative, philosophical ideas from the papers of Ed Ricketts are now available in the two volumes of *The Outer Shores*, edited by Joel Hedgpeth, and published by the Mad River Press (Route 2, Box 151-B, Eureka, CA 95501), at a price of $8.95 for Volume 1 and $9.95 for Volume 2. These volumes substantiate and enhance Ricketts' reputation as a biologist, which had already become established with the reissuing of *Between Pacific Tides*, a new edition of which was in press at his death. Additional material in the Hedgpeth volumes includes an essay on tide levels and biological zonation, and detailed logs of Ricketts' 1945 and 1946 expeditions to Vancouver Island and the Queen Charlotte Islands. These logs had been intended as raw material for a second Ricketts-Steinbeck collaboration. More detailed and sophisticated in their ethnological commentary than the Sea of Cortez log, they show Ricketts as a perceptive writer in his own manner, quite independent of Steinbeck. But after the car-train collision that killed Ricketts, Steinbeck decided not to go through with the project, commenting, "The light has gone out of it for me."

Joint Product

The Log from the Sea of Cortez is now a classic. However the title, and the alleged ambiguity about its authorship, need explaining. The version entitled "The Log From . . ." is not the raw log published in the Hedgpeth volumes, but the collaborative text by Ricketts and Steinbeck originally published in 1941—but without the phyletic catalog that was in the 1941 edition. The current edition is subtitled "The narrative portion of the book, *Sea of Cortez*, by John Steinbeck and E. F. Ricketts, 1941, here reissued with a profile 'About Ed Ricketts' by John Steinbeck." The book designer's setting of Steinbeck's name in large letters has misled many people into thinking that it is entirely by Steinbeck. But the subtitle is clear and accurate in its statement that the entire book, narrative and catalog alike, is the joint product of an artist and a scientist working in one of the closest, most unusual, and most creative collaborations of recent times.

Conclusion

In this timelessly beautiful book is presented a microcosm of the holistic man-in-nature theme that has emerged with such creative force in the past generation. As they tell the congenial story of their trip, in the long ago days of the Depression, Ricketts and Steinbeck draw parallels from the animal world to the human, and from both to the cosmological. They see the world as a grain of sand. It is a beautiful and deep vision, true to the organismic view of the interrelatedness of all existence. It is about this vision that John Steinbeck wrote in the foreward of the 1948 edition of *Between Pacific Tides*: "There are good things to see in the tide pools and there are exciting and interesting thoughts to be generated from the seeing. Every new eye applied to the peephole which looks out at the world may fish in some new beauty and some new pattern, and the world of the human mind must be enriched by such fishing."

Bruce Finson is a former editor of Pacific Discovery *magazine, published by the California Academy of Sciences. Katherine E. Taylor is a summer intern at* Oceanus, *published by Woods Hole Oceanographic Institution.*

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Hedgpeth, J. W. (ed.). 1978. *The Outer Shores*. Eureka, CA: Mad River Press Inc.

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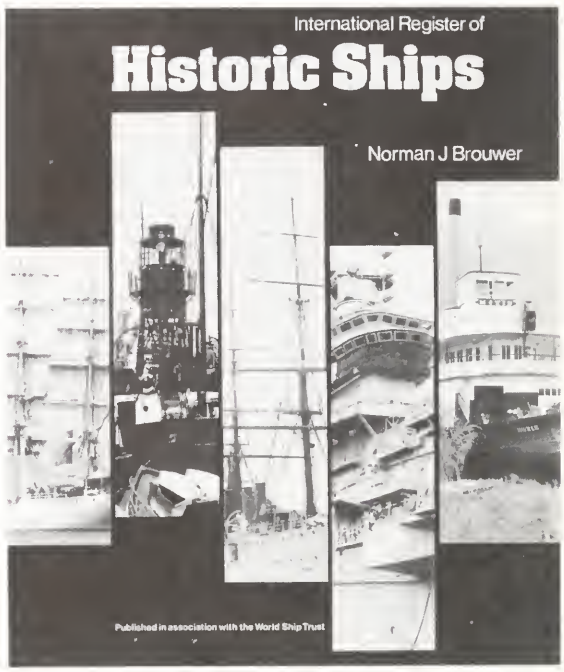
book reviews

***The International Register of Historic Ships* by Norman J. Brouwer. 1985. One Volume: 314 pp., 339 illustrations. Published in association with the World Ship Trust. Published and distributed in the United States by the Naval Institute Press, Annapolis, Maryland. $28.95.**



There have been more books written about ships than perhaps any other subject, but in taking its place among them the *International Register of Historic Ships* carves for itself a unique role. It is the first and only comprehensive work of its kind to be published. This is a book about ships that actually exist; ships that somehow have survived the ravages of ship-wrecks and wreckers, rot and rust, and are now being preserved as living histories in themselves.

The *Register*, published in association with the World Ship Trust, fulfills the first objective of that body—founded in 1979—"to compile an International Register of surviving historic ships and types of craft whether already preserved and exhibited or which otherwise may be considered as suitable for recovery, preservation, restoration and display."

The first edition contains a listing of 706 vessels located in 43 countries. It is the painstaking work of an eminent naval historian, Norman J. Brouwer, Curator of Ships at New York's South Street Seaport Museum. Brouwer's compilation dates back to 1962 with an initial list of 28 known vessels being preserved. The present number is the combined result of the author and his co-workers in maritime agencies and museums in many nations, and a growing awareness throughout the world that our maritime heritage is deserving of preservation.

The *Register* is systematically arranged alphabetically by countries and by current names of ships located within that country—not by country of origin. Statistics of each vessel are tabulated and include dates and place of construction, measurements, prior names, alterations, present location and condition, bibliography, and historical significance. In exceptional cases, there is an expanded discussion of the ship and/or its type class. Almost half of the listings have accompanying photographs. This, along with a pleasantly readable style, makes the book highly attractive to casual readers as well as scholars in maritime history. Inclusion in the *Register* is limited to intact vessels (not sunken)—40-feet or greater in length (except in special cases), currently being preserved for historic or educational value, or otherwise deemed to be of particular historic importance.*

Here we find almost with relief the names of ships which still are and will continue to be, ships like Liberty Ships of World War II, Grand Banks schooners, paddle-wheel steamers, square riggers, and many others whose preservation is assured. Dates of ships included within the *Register* range from 2500 BC—the Royal ship of Paroah Cheops—to 1961, the last steam tugboat built. Actually, only 12 vessels predate the 19th and 20th centuries. This tells us what boat owners have known right along—that the upkeep of old boats is a difficult and expensive proposition.

The 706 ship listings represent 41 nations, plus the Falkland Islands and South Georgia. The latter have been included because of several hulks of old ships in those waters. These include the oldest and probably last surviving American built square rigger. The author has led several expeditions in attempts to preserve the ships or at least slow their deterioration. Three hundred and forty three of the total listings are in the United States or Britain. Of the 184 U.S. listings, 21 are foreign built. Seven U.S. built ships are listed in other countries. Most of the ships listed are British built. This is especially true of the old square riggers where British yards started iron construction in the mid-1800s. Most American sailing ships continued as wood construction and as a result there are few old U.S. built ships remaining.

It is assumed that this first *Register* will stimulate additional listings to be submitted. Presently 101 maritime nations are not accounted for. This foreshadows future editions of hefty size.

To any nautical minded person—or at least to this reader—the *Register* stirs two emotions: 1) why some old favorites have not been included; and 2) profound regret over the passing of great ships or types of ships that did not survive. The first can still be rectified; the World Ship Trust states up front that it warmly welcomes suggestions and new submissions. Ships already gone have become a part of history written elsewhere. Our wondering why they

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* The readers of *Oceanus* might be interested in knowing that two venerable American oceanographic ships probably qualify for inclusion in the *Register*. The 142-foot sailing ketch *Atlantis*, built by Woods Hole Oceanographic Institution in 1930 and operated until 1966, is still afloat at Puerto Madryn in Argentina as *El Austral*, a research vessel for the Argentine Science Council. It gave its name to the space shuttle *Atlantis*. The 202-foot three-masted schooner *Vema* operated by Lamont-Doherty Geological Observatory of Columbia University from 1953–81, was built in 1923 as the yacht *Hussar* and is now the passenger cruise ship *Mandalay*. Both ships did historic research work, including much of the early field work for the continental drift theory.

were not saved cannot bring them back. The venerable aircraft carrier *Enterprise*, thought by many to be the greatest warship ever; the old four-stack destroyers; the old racing yacht *America* of Cup fame; and others all deserved better. By bringing these thoughts to mind, the book well serves its cause in fostering the preservation of our remaining ships.

On examination the reader might be inclined to ask if all listings are really historic. Should 17 American oyster boats dating through 1955 really be given a place? And what about 23 World War II submarines and 24 lightships? The answer depends on the commitment by the preserver that these ships will indeed be maintained as a heritage for future generations.

The work obviously has strived for impeccable accuracy which the calibre of the listings clearly demonstrate. Occasional slips, either unintentional or otherwise, emerge. The four-masted barque *Kruzenshtern* (USSR) is listed as a training ship – which it is—but the format of the book intends that each ship be classified by its original use. It is only briefly mentioned that the *Kruzenshtern* was the last deep water commercial square rigger built. The *USS Constellation* is listed totally separate from the 1797 origin claimed by its owners and supported by U.S. Navy records. Although its keel and main timbers are original, it was more than 50 percent rebuilt in 1855, which under U.S. policy makes it new. Under British or French policy, it would be otherwise. The controversy will continue regardless of the attempt by the author to close it out.

The *International Register of Historic Ships* will become, if it is not already, the "official" world listing of historic vessels. By its very content and style, it is an essential part of any nautical bookshelf.

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***The Botany of Mangroves* by P. B. Tomlinson. 1986 Cambridge University Press, New York, NY. 413 pp + xii. $69.50.**

Almost anywhere one chances to be along tropical shores, the water's edge will be lined by a prominent fringe of mangrove trees. The "fringe" can in fact have impressive dimensions in height (up to perhaps 30 to 40 meters tall), and horizontal extension. Some mangrove stands extend for hundreds of kilometers along the shore and reach back as inland wetlands for very considerable distances.

People have held a love-hate relation to wetlands for as long as the two have co-existed. Some of the benefits of such wetlands are common knowledge. It is no secret to coastal fishermen that fish are plentiful near mangrove areas; the trees themselves have long been used as a subsistence-level source of charcoal. More recently mangroves have been cut for sawn poles and timber; the wood thus obtained has such high concentrations of tannins that it is resistant to borers and termites, and has a high density appealing to carpenters. There have been traditional uses of the chemical properties of mangroves: the abundant tannins found in the trees have been extracted to use in the manufacture of leather; Polynesians extract black dyes from mangrove sap for their manufacture of tapa cloth.

Almost all such uses of mangroves have been at a subsistence or perhaps low technological level and only marginally affect mangrove swamps. It is only recently that more prominent human activities have led to heavy damage to the world's mangroves. The rich sediments and waters of mangrove swamps have prompted conversion of many hectares of mangrove estuaries to impounded ponds designed for mariculture of shrimp and fish, as in Ecuador, the Philippines, and Indonesia, and for rice paddies in Sierra Leone. Throughout the Caribbean, development of marinas, hotels, refineries, and so on have taken place on what was mangrove swamp. Very little institutional protection stands in the way of destruction of mangrove swamps, and the acreage is being steadily reduced. There are at least two reasons for the lack of protection. First, there is precious little pressure for conservation in most of the countries involved, and what there is is hardly aimed at mangroves. In some areas of Brazil, for example, mangrove swamps are inhabited by people on the lowest rungs of the economic and social ladder; mangroves are thus viewed as a refuge for outcasts and the destitute, certainly not an environment of major priority in the mind of the country's policymakers. Second, there is too little knowledge of the actual compelling importance of mangrove swamps. An appropriately convincing set of factual arguments, including, for example, the role of mangroves in supporting economically important fisheries, would be invaluable as a means to influence policy, but the research base for such arguments is not well developed.

The case needs to be made, therefore, for much study of the basic functioning and applied importance of mangrove swamps, and the need to carry out work quickly

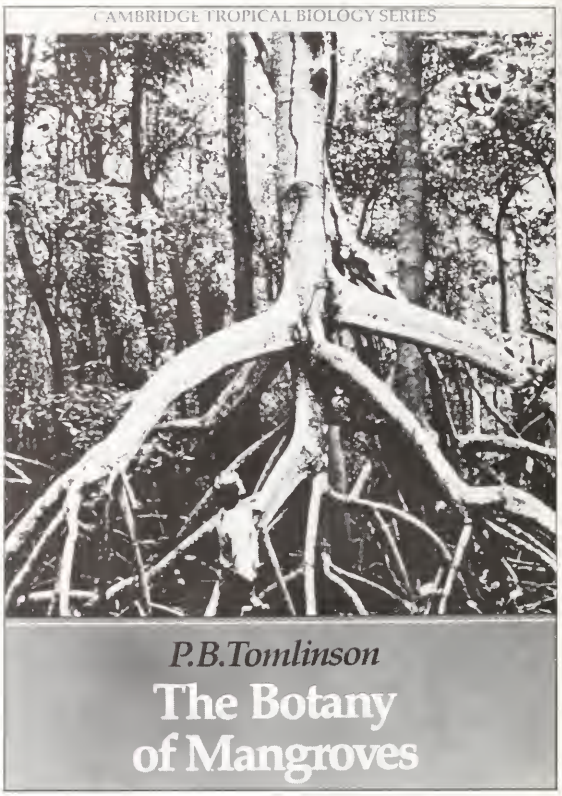
before much more destruction takes place. Educational campaigns also will be needed to raise awareness of mangroves as a resource that contributes to the human landscape.

Two Books in One

To start the education process, it is good to have references such as the book by Tomlinson, *The Botany of Mangroves*. This actually is two books in one. The first part deals in a scholarly fashion with selected topics—mainly a description of plant parts, a bit of geography, and a little of how these plants work. Tomlinson says that he omitted the environmental aspects because of the availability of publications on that topic. The omission is unfortunate, because it would have been helpful to have the ecological and natural history insights of the author, clearly an individual with extensive field experience. Articles reviewing the ecology of mangroves, moreover, have appeared in technical journals of only limited distribution. The ecological aspects also would have provided a better context for various now disjointed chapters, especially the one on use and exploitation, the one chapter which the general reader will appreciate most.

The second and longest part of the book is an account of each family and species of mangroves, including taxonomic keys with which to identify the plethora of very similar species. The magnificence of biological diversity, in this case, of a remarkable "variation on a theme," a theme that is in fact fundamentally simple, is a major impression that emerges from the taxonomic section, aided by very fine ink drawings, some quite beautiful, of the many mangrove species. There are photographs, but they are only adequate—in the author's defense, I must add that is it frustratingly difficult to photograph in mangrove swamps. The detailed accounts of families and species in this second section of the book will be useful to the specialized reader with museum specimens in hand, but less so to the lay reader. The book is too bulky and the taxonomic keys too interspersed with other material to use effectively as a field guide. There are very few obvious errors and the layout is very pleasing. The emphasis on morphology, the scant process-oriented material, plus the taxonomic nature of the second part of the book impart a slightly dated tone to this book, but a tone assured by competence and scholarship.

One hopes that this and other books help scientists, educators, and decision makers take up and meet the challenge of education that is essential to preserve mangrove swamps. These environments provide tropical coasts with subsidies—protection against coastal erosion



and flooding, nurseries for wild life, nutrient rich waters for coastal marine species, removal of wastes from contaminated waters—all of which require only conservation of the integrity of the environment, not costly technical fixes, nor high-technology exploitation schemes. As Tomlinson concludes, it is most likely that the best image of use of mangroves as a resource to be sustained in perpetuity is that of a woodcutter puttering his way through mangrove creeks with his just-cut load of firewood in a shallow-draft boat.

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***Wandering Lands and Animals, The Story of Continental Drift and Animal Populations* by Edwin H. Colbert. 1985. Dover Publications Inc., New York, NY. 323 pp. + xxv. $7.95.**

This Dover edition is an unabridged but slightly corrected version of *Wandering Lands and Animals* published by E.P. Dutton & Company, Inc., New York, in 1973. Edwin Colbert, well known as a paleontologist and the former Curator of Vertebrate Paleontology at the American Museum of Natural History, has produced a book that tells how the mammal populations and their distribution on Earth have changed from the Paleozoic Era until the present day. He draws heavily upon his fossil collecting experience, especially in Antarctica, and his worldwide knowledge of vertebrate fossils.

A recurring theme is his identification of bone fragments of the early Triassic fresh water reptile *Lystrosaurus* in Antarctica and the key role this fossil played in supporting the concept of continental drift in the minds of many paleontologists. In fact, his first chapter differs from the remainder of the book in being a personal account of his identification of a bone fragment brought by Peter Barrett from Antarctica and Colbert's later trips to the Transantarctic Mountains to collect more specimens. He had collected the same fossil in India and Africa and its presence in Antarctica clearly indicated a common land connection during a time when these creatures lived.

His description of the super-continent Pangaea, the large northern continent, Laurasia, and the large southern continent, Gondwanaland, starting in the mid Paleozoic, is rather cursory but, as he says, the main purpose of this book is to describe the time and spatial distribution of mammal populations. He jumps right in describing the different fossil animals in different places and at different geologic times. Since neither the history of a particular creature nor its spatial distribtion are continuously known, one is presented with numerous species names and a goodly number of geologic places tied together with hypotheses. To keep all of the names straight, an 11 page glossary is provided and there are copious line drawings and photographs. Taken a chapter at a time, the reading is fascinating, but taken as a whole, it can be heavy going.

An especially interesting section tells of the isolated faunal development of India, Australia, and South America during the early Tertiary when none of these were in touch with other landmasses. He also shows how the development of land bridges during the Pliocene and Pleistocene permitted the migration of animals, especially between eastern and western Eurasia and the Americas. The discussion carries on through the Ice Ages and the appearance of man, and how the animal population has been altered by man. There has been an extinction of large mammals in North America in the last 20,000 years, for which man is at least partly responsible. Over the same time man's domestic animals have become the most common ones found on earth.

Recent developments are not covered by the book. These include the paleoclimatic information derived from marine microfossils and the great debate that is raging about the relationship between the extinction of the dinosaurs and the origin of the iridium layer found at the Cretaceous-Tertiary boundary. Very little evidence from paleo-botany is cited. Also it is disconcerting that the size of the famous *Lystrosaurus* is not given (this reviewer was surprised to see a model of it at the National Science Foundation and find that was a mere foot in length).

This paperback falls somewhere between a paleontology text and a popular book, but is outstanding for its comprehensive overview of animal populations.

J. R. Heirtzler,
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Biology

Aquatic Microbiology, Third ed. by G. Rheinheimer. 1985. John Wiley and Sons Ltd., New York, NY. 257 pp. $32.95.

A Functional Biology of Marine Gastropods, by Roger N. Hughes. 1986. The Johns Hopkins University Press, Baltimore, MD. 245 pp. $32.50.

Chemistry

Water Science Reviews I, Felix Franks, ed. 1985. Cambridge University Press, N.Y., N.Y. 232 pp. Price Unavailable.

Environment/Ecology

The Oregon Oceanbook by Tish Parmenter and Robert Bailey. 1985. Oregon Department of Land Conservation and Development, Salem, OR. Available through The Bookstore, Oregon State University, Newport, OR. 85 pp. $6.00 (+ $1.25 shipping and handling).

Washington Public Shore Guide: Marine Waters, by James W. Scott and Melly A. Reuling. 1986. University of Washington Press, Seattle, WA. 348 pp. $25.00 (hard-cover), $14.95 (paperback).

Lecture Notes on Coastal and Estuarine Studies: Plankton Dynamics of the Southern California Bight, Richard W. Eppley, ed. 1986. Springer-Verlag, New York. 373 pp. + xiii. $31.40.

The Cape Cod National Seashore (A Landmark Alliance) by Charles H. W. Foster. 1985. University Press of New England, Hanover, NH. 125 pp. + xii. $8.95.

General Reading

Biophilia by Edward O. Wilson. 1984. Harvard University Press, Cambridge, MA. 157 pp. $15.00.

California Currents: An Exploration of the Ocean's Pleasures, Mysteries, and Dilemmas by Marie De Santis. 1985. Presidio Press, Novato, CA. 238 pp. + x. $15.95.

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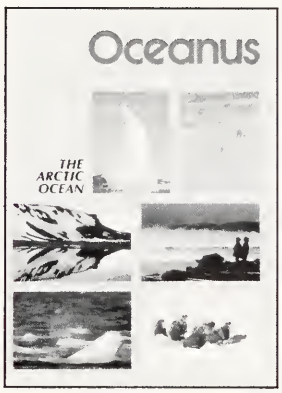

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Video images of *Titanic* light fixture, above, and hull section with rattail fish, right.